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THE ORIGIN OF THE LEAD AND ZINC ORES OF THE UPPER MISSISSIPPI VALLEY DISTRICT.

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PART I.

The large amount of lead and zinc ore that has been extracted from the upper Mississippi Valley district, extending over a period of nearly a century and a quarter, together with the comparatively simple geology and the absence of igneous rocks, makes the origin of the lead and zinc ores of this district of special interest. From the time of Percival and Owen, who believed the ores to have been derived from igneous rocks below, to that of the present writers, such as Chamberlin, Van Hise, Grant and Bain, who believe the ores to have been concentrated from the sediments, there has been a continued change of ideas.

GEOLOGY.

STRATIGRAPHY.

The geology of the district is simple, both as to the variety of rocks present and in their relations to each other. All the rocks exposed at the surface are of sedimentary origin. Crystalline rocks underlie the whole area at a depth of 1,500 to 2,000 feet.

The following is a general section for the district.

No trace of rocks younger than the Niagara dolomite has been found in the district. If they ever existed all trace of them has been removed. A few remnants of the Niagara dolomite and

System.	Formation.	Character.	Thickness in Feet.
Quaternary.		Residual clays. Alluvium. Terrace deposits. Loess.	0 to 80
Silurian.	Niagara.	Dolomite.	120±
Ordovician.	Maquoketa.	Shales, with some limestone.	140 to 175
	Galena.	Dolomite.	240 to 260
	Platteville.	Limestone and dolomite.	60
	St. Peter.	Sandstone.	100
	Lower Magnesian.	Dolomite and sandstone.	330
Cambrian.	Potsdam (includes St. Croix).	Sandstone with some shale and dolomite.	1,000
Pre-Cambrian.		Various igneous and metamorphic rocks.	

the Maquoketa shale have so far withstood the attack of erosion and are to be seen as isolated mounds composed of shale with a cap of resistant dolomite. The Galena dolomite directly underlies the greater part of the area, although in the northern portions there are outcrops of the Platteville and St. Peter formations, and even of the Lower Magnesian dolomite. Those rocks lying below the Potsdam sandstone have not been reached by the deepest wells, so that their presence is only known from their occurrence at neighboring points.

Descriptions of the Potsdam, Lower Magnesian, St. Peter and Niagara formations, not having any direct bearing upon the origin of the ores, have been omitted.

Platteville Limestone.—The Platteville formation lies upon the St. Peter sandstone. It varies in thickness from 40 to 65 feet, and is probably the purest limestone in the Paleozoic series of this region. It has usually a light bluish color when fresh, but weathers to a light buff. Where unaltered the beds have a firm, compact texture and may all appear massive but on exposure the upper beds break up into thin shaly layers which may be separated by clay partings. The lower massive beds are known as the "lower buff limestone" or "quarry beds," being extensively used for quarry purposes. A general section of the Platteville limestone, following Grant,[1] is given below.

[1] Wis. Geol. and Nat. Hist. Survey, Bull. 14, p. 31.

GENERAL SECTION OF THE PLATTEVILLE LIMESTONE.

	Feet.
4. Thin beds of limestone and shale	10–20
3. Thin-bedded, brittle, fine grained limestone	15–25
2. Thick-bedded, magnesian limestone or dolomite	15–25
1. Blue shale, sometimes sandy	1– 5

No. 1 marks the division between the St. Peter sandstone below and the Platteville limestone above. In general this clay bed seems to thicken towards the west. It is absent at Mt. Horeb, Wis., and Rockton, Ill., and varies from 1 to 5 feet in thickness at Lancaster, Wis., thinning out to the north. It is reported[1] as being 2 to 3 feet thick in eastern Iowa. No. 2 is a slightly dolomitic limestone, somewhat porous but which can usually be distinguished from the other Platteville strata above by its thick, massive bedding, and from the Galena dolomite by its smaller porosity and less irregularly weathered surface. These are the so called "lower buff" or "quarry" beds and vary from 8 inches to 3 feet in thickness. No. 3 usually occurs in thin, wavy, shale-like layers about two inches thick, often separated by thin clay partings but may at times be massive, especially where not weathered. In places these beds approach the glass rock beds of no. 4 in character and composition, although more thinly bedded. No. 4 consists essentially of thin shaly limestone and thin seams of shale, both of which are very fossiliferous. This includes the main glass rock beds and the so called glass rock opening, the name applied to a portion 2 to 3 feet thick directly below the main glass rock beds. The ores sometimes occur, "make," in this "opening" which then consists of either a clay bed or thinly bedded limestone. Towards the west there is a tendency for the thin shaly beds to be replaced by clay. At Mineral Point, Wis., there is about 2 feet of clay below the glass rock; at Cassville, Wis., 2 feet; at Potosi, Wis., 6 feet; at Dubuque, Ia., 1 foot; and at Rockton, Ill., none.

From 3 to 10 feet below the top of the formation, near the center of no. 4 as given above, occurs a stratum of hard, compact, chocolate-colored rock varying from 6 inches to 5 feet in thick-

[1] "Geology of Iowa," Vol. 1, pt. 1, p. 57.

ness and locally known as the "glass rock." The extent of the glass rock, like that of the oil rock (see p. 431), corresponds rather closely to that of the lead and zinc district. Variations in thickness, while not as marked as in the oil rock, are still common. In Wisconsin it is absent at Mt. Horeb but abundant at Dodgeville. It is thin at Monford but thick at Lancaster. In the vicinity of Highland it varies from 8 inches to 5½ feet, being 5 feet thick at the Kennedy mine. It is poorly developed at Bagley and Glenhaven but prominent at Cassville and Potosi, Wis. It is present at North Buena Vista, Specht's Ferry, and Dubuque, Ia., and Galena, Ill., but absent at Rockton, Ill. It is a hard, compact, fine-grained rock, breaking with a conchoidal fracture and occurs in bands from 2 to 6 inches thick. Chemically it is a rather pure limestone, consisting of over 85 per cent. $CaCO_3$.

In the northern portion of the Wisconsin field where the oil rock is near the surface or has been eroded, considerable ore has been found associated with the glass rock, but in the southern portion of the field no ore in paying quantities has been found at this horizon.

Galena Dolomite.—This is the main ore-bearing formation of the district, the ore being found mostly in the lower half, the upper part having been largely eroded except in the southern portion of the area. In general it is a porous, magnesian limestone approaching a true dolomite in composition.

A general section from the top down as given by Grant and Burchard[1] is as follows:

	Feet.
5. Dolomite, earthy, thin bedded	30
4. Dolomite, coarsely crystalline	60
3. Dolomite, thin to thick bedded, coarsely crystalline, chert bearing	90
2. Dolomite, thin bedded, coarsely crystalline	50
1. Thin bedded limestone with shaly partings which are highly fossiliferous and, in part at least, carbonaceous—the "oil rock" of the miners	2 to 10

Perhaps the most characteristic features of this formation are

[1] U. S. Grant and E. F. Burchard, U. S. Geol. Survey Folio No. 145, 1907, p. 6.

its dolomitic character, porous structure, and roughly weathered surface at outcrops,—thus differing quite markedly from its associate, the Platteville limestone. The formation as a whole contains many fossils, of which *Receptaculites oweni* has been found to characterize certain horizons and to be of considerable use in locating points within this formation. This, although a species of the sponge, resembles a coral for which it is often taken. Although a few of these specimens are found throughout the entire thickness of the dolomite, it is particularly characteristic of two zones about two feet thick which occur near the top and bottom of the flinty layer no. 3, and which are known as the upper and lower Receptaculites respectively. The first is about 30 feet below the top of no. 4 and the second 35 to 50 feet above the main oil rock bed, the lower portion of no. 1.

Oil Rock.—Occurring at the base of the Galena dolomite and sometimes as partings between the thin glass rock-like beds of the upper portion of the Platteville limestone and the lower ten feet of the Galena dolomite, is a dark organic shale known as the "oil rock." The base of the main body of oil rock occurring from 8 to 12 feet above the glass rock is taken as the division between the Platteville limestone below and the Galena dolomite above. Chamberlin placed the contact at this horizon because of what he considers to be a slight unconformity at this point, and Ulrich because it marks the greatest paleontological break in the Galena-Platteville series. Interbedded with, or just below, there is often a greenish clay bed a foot or so in thickness. This clay bed is the most prominent in the western portions of the district. It has been reported by both the State Geological Surveys of Iowa and Minnesota. It is a common thing for miners to report as oil rock the main oil rock bed, the clay bed below it, and the thinly bedded glass rock-like limestone with oil rock "partings," which accounts for the reports of 10 or 20 feet of oil rock, when the actual amount of organic shale may be less than a foot.

When wet the oil rock is of a dark chocolate color, but when dry it is a light clay-gray, recognized by its usual laminated structure and by the fact that it will burn. In drilling it is recognized

by the color of the cuttings and by the appearance of oil upon the water. Thin seams of oil rock are at times found at higher levels in the Galena dolomite, but their presence has no known significance. It is to this thin bed of organic shale that many believe the presence of ore in the district is due. Its general distribution and thickness is shown by Plate XI.

Maquoketa Shale.—There are no good exposures of the shales within the Wisconsin portion of the lead and zinc field, the best exposures being found in southeastern Iowa, as at Dubuque, Julien and Graf, and northwestern Illinois, as at Elizabeth, Stockton, Scales Mound, Apple River, etc. The lower portion of this formation as it appears at Julien, Ia., Elizabeth, Apple River and Stockton, Ill., consists of alternate bands of a bluish shale and limestone as shown in the accompanying cuts. At the Granville mine, north of Scales Mound, Ill., about 30 feet of the shale is exposed to view. Here also it consists of a light blue shale with 2- to 4-inch beds of limestone, although these interstratified bands are more widely spaced than in the lower portions of the formation. Pieces of sphalerite easily discernible with the naked eye occur in these shales, associated with pyrite and barite.

The following sections were made by Calvin and Bain:[1]

Section of Maquoketa Shale at Graf, Iowa.

	Ft.	In.
17. Drab to black, argillaceous, unfossiliferous	2	
16. Sixth Orthoceras bed; brownish, hard, granular, nonfissile shale, with numerous specimens of the minute, brad-like shells of *Coleolus iowensis*, some small gasteropods, a few specimens of *Orthoceras sociale*, together with cephalic shields and pygidia of *Calymene mamillatus*	1	2
15. Shale, drab, very fissile, somewhat sandy, no fossils	1	4
14. Fifth Orthoceras bed; light brown, earthy, nonlaminated, rather hard layer, which some writers have described as limestone; not very calcareous; crowded with shells of *Orthoceras sociale*, which are generally crushed and otherwise imperfect, some of the partially decomposed shells still retaining the original nacreous luster	1	
13. Fissile, slaty shale, dark gray in color, containing many blade-like or sheath-like impressions of *Spatiopora iowensis* Ulrich		6

[1] "Geology of Iowa," Vol. 10, pp. 180–182, 1900.

12.	Fourth Orthoceras bed, lithologically the same as no. 14; *Orthoceras* very numerous and crowded, more perfect than in 14	6–8
11.	Shale varying in thickness, dark gray in color	1–3
10.	Third Orthoceras bed, resembling 12 and 14	10
9.	Thin bed of dark, fissile shale; irregular as to thickness, in some places reduced to a mere parting	1–3
8.	Second Orthoceras bed, lithologically like 10, 12 and 14	1
7.	Shale, dark brown, imperfectly laminated, rather coarse grained and earthy, crowded with *Diplograptus peosta*	5
6.	First Orthoceras bed, like no. 8	4–8
5.	Shale, brown, fissile, fossiliferous	7
4.	Shale, earthy, granular, nonlaminated, with many comminuted fossils and perfect shells of *Coleolus iowensis, Murchisonia gracilis, Liospira micula* and other species	2
3.	Shale, dark brown, nonfissile, with a species of *Lingula* three eighths of an inch long and one fourth of an inch wide	2
2.	Shale, dark bluish-black, fissile or slaty, containing large numbers of *Leptobolus occidentalis* and two species of *Lingula*	2 2
1.	Shale, brown or black, nonfissile fossils rare, occasional specimens of a *Lingula* half an inch long and three-eighths of an inch wide	6

Apparently the lowest beds of the Maquoketa are not represented in this section.

The lower portion of the shales is, at least in places, inclined to be more organic than the upper, and also to carry a greater amount of iron sulphide, which may be more or less oxidized. At places the shales become very organic as at Elroy and Mt. Carroll, Ill., where they contain as high as 20 per cent. organic matter. It was this character that first led to their consideration as a possible source of the ores, which consideration has been farther strengthened by the finding of ore in the highly organic shales of Elroy and Mt. Carroll and in the light blue shales of Elizabeth, Stockton, Scales Mound, Hanover and Galena, Ill., and Dubuque and Graf, Ia., etc.

STRUCTURAL GEOLOGY.

Oil Rock Basins.—The contour map of the oil rock horizon, based upon drill records and mining data, has the appearance of

a district which has been complexly folded, the major thrust of which acted in a nearly north and south direction. Just what portion of these inequalities are due to deposition with initial dip caused by the unevenly eroded surface of the Lower Magnesian dolomite, and what portion to folding is uncertain. That an unconformity exists between the St. Peter sandstone and the Lower Magnesian dolomite and that a drainage system had been at least partly established before the deposition of the sandstone seems certain. Yet it is not clear how these irregularities, carried upward in an increasingly modified form by the deposition of the sandstone and limestone, could produce basins. The movements that have taken place in the oil rock, as shown by compression and stretching of the beds, are such as might result from the folding of a thin, incompetent bed of shale between two hard, competent layers of limestone, such as the Platteville and Galena formations. However, the base of the Maquoketa shale, although varying in elevation from place to place, does not have the variation shown by the oil rock. This indicates that either the oil rock basins were formed only in part by folding or that the folding took place largely before the deposition of the shales. Grant concludes that, "It is quite probable, . . ., that in very many cases inequalities in deposition have been accentuated by folding since the rocks have solidified."[1]

It therefore seems logical to conclude that the contour of the oil rock horizon represents a vertical projection of the erosion surface at the top of the Lower Magnesian dolomite modified by sedimentation and folding.

GENESIS OF THE ORES.

REVIEW BY AUTHORS.

Like others of his time Owen[2] believed that ores in general were derived directly from igneous rocks; that in the Wisconsin district such rocks had been intruded after the deposition of the sediments which now contain the ores; and that the ore-bearing

[1] U. S. Geol. Survey, Bull. 294, p. 41.
[2] Owen, D. D., "Geology of Wisconsin," Vol. 4, p. 77, 1882.

solutions and gases given off by these rocks escaped upward along faults and fissures, resulting in the deposition of the ores in the formations above.

While the later developments have confirmed the presence of crystalline rocks below within the depths postulated by Owen, they have failed to show the presence of faults and deep fractures and of any igneous rocks younger in age than the ore-bearing formations. In fact the evidence all goes to prove that the igneous rocks are very much the older. It has also been shown that between the igneous rocks and the ore-bearing strata there are a number of clay bands which would make the ascension of ore-bearing solutions and gases very difficult if not impossible.

Percival[1] agreed with Owen in the belief that the ores were derived from below. Apparently his chief reason for so thinking was the occurrence of galena in considerable traces in the Lower Magnesian dolomite north of the Wisconsin River. He believed that workable deposits would be found in this formation.

Whitney[2] advanced an hypothesis of sedimentary origin for the ores, upon which practically all the later theories are based. He believed that for some unknown reason the sea of each geologic age was richer in these elements than any later sea; that the ores were precipitated from the sea by the reducing action of hydrocarbons, largely from the decay of the bodies of marine animals whose shells form the limestone, and in part from weeds which grew on the sea bottom, so that the metallic compounds were scattered throughout the formation in very finely divided particles, to be later concentrated by ordinary meteoric waters. He recognized the importance of secondary concentration in the localization of the ore bodies, but also appealed to local enrichment of organic matter to account for this. According to Chamberlin[3] this theory would require that:

1. The metallic deposits should correspond to the introduction and distribution of life.

2. The ores should appear in the strata where life first appeared.

[1] Percival, J. G., Ann. Rept. Geol. Survey Wisconsin, 1855, pp. 7–101.
[2] Whitney, J. D., Geol. Surv. Iowa, Vol. I., Pt., I., pp. 422–471.
[3] Chamberlin, T. C., "Geology of Wisconsin," Vol. IV., 1873–1879, p. 372.

3. The ores should be abundant or sparse, according to the luxuriance of life.

4. The ores should continue prevalent in the life-bearing beds till the oceanic supply was exhausted, when they would cease.

None of these conditions are filled by the occurrence of the ore bodies.

The points of this theory which are of essential interest to us at the present time is the derivation of the ores by the leaching of the pre-Cambrian crystalline rocks to the northeast; the transportation of the dissolved material to the Paleozoic sea by streams; the precipitation of the ores from the sea by the reducing action of hydrocarbons; their deposition with the Paleozoic sediments; and their later concentration by meteoric waters.

Chamberlin's report[1] for the State of Wisconsin contains the most complete description of these deposits yet published. For the precipitation of the ores from the sea he appeals to the reducing action of hydrocarbons resulting from the decay of organic matter, but organic matter of a vegetable nature rather than that of animal. He finds the source of these decomposition products largely in the so-called oil rock at the base of the Galena formation. He shows how the oil rock may have resulted from vegetable accumulations in a sargasso-sea and how the sea may have been locally enriched in lead and zinc in the same manner. Computations are given tending to show that the percentage of lead and zinc in the Galena formation necessary to account for the concentration of the richest known ore bodies was very small, "one fourteen-hundredth of one per cent." A relation between the ore deposits and the oil rock basins is recognized and explained by assuming that the depressions of the present oil rock basins existed on the bottom of the Galena sea, and that the oil rock, and therefore the ore, accumulated thicker in these basins than elsewhere. By this theory the ore is assumed to have existed in the Galena formation as very fine particles in a disseminated condition and to have been later taken into solution by

[1] Chamberlin, .T C., "The Ore Deposits of Southwestern Wisconsin," "Geology of Wisconsin." Vol. 4, 1882, pp. 365–571.

ordinary meteoric waters, assisted largely by humic acids, as it percolated down through the small pores of the limestone, carried laterally to openings, and there precipitated by organic matter washed in from the surface.

Two possible explanations are offered to explain the vertical distribution of the ores.

1. The lead was originally precipitated in the upper and the zinc in the lower portion of the Galena formation and each has been concentrated within its horizon.

2. The vertical distribution represents the order of deposition from ascending solutions.

Blake[1] followed Whitney in believing that the ores were derived from the surrounding contemporaneous sediments and their localization as due to local abundance of organic matter; and Chamberlin by deriving the organic matter from the oil rock and not from the decaying bodies of crustaceans. In fact his main contribution was not in suggesting something new, but in calling attention to the significance of the oil rock which had been previously suggested by Chamberlin. He also called attention to the close coincidence of the boundaries of the lead and zinc district and the Driftless Area, but offered no explanation.

As Chamberlin and Blake had followed Whitney, so Jenney followed Percival, considering the ores to be of a direct igneous origin, having come up through faults and fissures which controlled their lateral distribution.[2]

Winslow made a close study of the lead and zinc ores of Missouri, especially those of the Ozark region, and reached the conclusion[3] that the ores were derived from above by the decomposition and erosion of superimposed strata and concentrated by descending meteoric waters. Buckley and Buehler[4] have recently come forward in support of this hypothesis as applied to the Missouri lead and zinc deposits.

[1] Blake, W. P., *Bull. Geol. Soc. Am.*, Vol. 5, 1894, pp. 25–32; *Trans. Am. Inst. Min. Eng.*, Vol. 22, 1893, pp. 558–568, 621–635.

[2] Jenney, W. P., Paper read before a meeting of the American Institute of Mining Engineers in 1893, p. 14.

[3] Winslow, Arthur, Missouri Geological Survey, Vol. 7, 1894, pp. 477–487.

[4] Buckley and Buehler, Missouri Bureau of Geology and Mines, Vol. 4, 2d series, 1905.

From his work for the Iowa Geological Survey, Leonard concluded that the theory of origin and concentration as outlined by Chamberlin "furnishes, on the whole, the most plausible explanation yet offered for the localization of the upper Mississippi deposits."[1] He also calls attention to the seemingly impossible concentration of the ores from formations above as advanced by Winslow, because of the thick and impervious Maquoketa shale which overlies the Galena dolomite.

In 1900 Calvin and Bain,[2] from their work for the Iowa Geological Survey in the vicinity of Dubuque reached practically the same conclusions as previously outlined by Chamberlin. They made a series of analyses of limestones and dolomites after the manner of those made by Winslow to show the general presence of lead and zinc in disseminated form in the country rock.

In 1901 Van Hise discussed[3] some of the principles controlling the deposition of ores and applied them to this district. He agreed with Whitney and Chamberlin in the primary origin of the ores, their precipitation from the sea, and their deposition with the Paleozoic sediments; but appeals to an artesian circulation to account for their concentration. The oxidizing water enters the southward dipping strata where they are exposed at the surface to the north, passes downward and laterally through the small pores and along joints and bedding planes, dissolves the disseminated mineral of the formation, and finds an outlet to the south where the Maquoketa shale has been eroded.

R. E. Davis[3] advanced the hypothesis that the ores were pre-

[3] Thesis, University of Wisconsin, 1906.

cipitated from the Ordovician sea by the hydrocarbon decomposition products of the oil rock, and that therefore the ores were originally contained within the oil rock, and that they were taken into solution by fatty acids from the oil rock, carried upward and precipitated in the openings of the formation above.

He agrees with Chamberlin in that the oil rock is supposed to

[1] Leonard, A. G., Iowa Geol. Survey, Vol. 6, 1896, p. 61.

[2] "Geology of Dubuque County," Iowa Geol. Survey, Vol. X., 1900, pp. 370–622.

[3] *Trans. Am. Inst. Min. Eng.*, Vol. 30, 1901, pp. 27–177.

have been formed in a sargasso sea and with Chamberlin and Blake in the precipitating power of the organic acids and gases given off by the same. He shows that the ores are soluble in organic acids and that their precipitation from ascending solutions of the same would give the following order of minerals, starting at the bottom—marcasite, galena, sphalerite.

In 1906 Bain published his theory of origin[1] of the lead and zinc ores of this district. While proposing practically nothing new in theory, he has combined the better portions of the various theories and has advanced considerable evidence to support this new arrangement. He follows Whitney in the primary origin of the ores and Chamberlin in their manner of precipitation, but surpasses both of these in the amount of detailed evidence pertaining to the origin of the ores.

In 1903,[2] 1905[3] and 1906[4] Grant prepared bulletins for the Wisconsin Geological and Natural History Survey and the United States Geological Survey, in the first of which he discussed the origin of the ores in accordance with the ideas earlier presented by Van Hise. In 1907[5] he prepared a folio for the United States Geological Survey in which he briefly outlined the origin of the ores giving the same theory as previously published by Bain in 1906.

Leith,[6] like Chamberlin, believes the ores to have been precipitated from the Ordovician sea by the organic compounds given off by the oil rock, but does not think that the ore particles were all finely disseminated or uniformly distributed through the formation. He thus differs from all others, at least in so far as they have committed themselves, in believing that some, at least, of the

[1] Bain, H. Foster, "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey No. 294.

[2] "Lead and Zinc Deposits of Southwestern Wisconsin," Bull. Wis. Geol. and Nat. Hist. Survey, No. 9, pp. 103.

[3] "Zinc and Lead Deposits of Southwestern Wisconsin," Bull. U. S. Geol. Survey, No. 260, pp. 304–310.

[4] "Lead and Zinc Deposits of Wisconsin," with atlas of detailed maps; Bull. Wis. Geol. and Nat. Hist. Survey, No. 14, pp. 100.

[5] Grant, U. S., and Burchard, E. F., "Description of the Lancaster and Mineral Point Quadrangles," Folio U. S. Geol. Survey No. 145, pp. 14.

[6] Unpublished article.

ore deposits represent original concentrations by direct precipitation from the Galena sea.

According to the Galena-Oil Rock theory, as advanced by Bain[1] and Grant, the Ordovician sea in which the Galena limestone was formed contained these metals in solution. During the formation of this limestone the decomposition of the organic matter in the oil rock below produced organic acids and gases which rose up through the then unconsolidated material into the sea and caused the precipitation of the lead, zinc and iron compounds held in solution, so that minute particles of the sulphides of these metals were scattered throughout the beds of the Galena during the course of its formation. After the deposition of this and the superimposed formations, the sea retreated, the area became dry land, and the overlying formations were eroded. Following the exposures of the Galena limestone as the result of this erosion, the disseminated ore particles were taken into solution by ordinary oxidizing water from the surface as it percolated through the limestone (which was probably undergoing dolomitization at this time), carried laterally to openings and there deposited, where it may have since undergone one or more secondary concentrations.

The present ore bodies are believed to have been formed mainly by the reduction of sulphates to sulphides as a result of the mingling of solutions and reactions between ore-bearing solutions and organic matter in the country rocks. To a subordinate degree the sulphurization of carbonates has probably taken place. It seems altogether likely that the original precipitation of the materials from the sea water occurred through the same reactions. If this be true, an original localization of the material may have been due to—

(*a*) Local abundance of the metals in solution.

(*b*) Local abundance of the organic reducing matter.

(*c*) Locally peculiar organic matter, leading to particular efficiency in producing deposition.[2]

Under "Local Abundance of the Metals in Solution" attention is called to the fact that the lead and zinc minerals are unequally

[1] Bain, H. F., "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey No. 294, p. 129.

[2] Bain, H. Foster, "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey No. 294, p. 133.

distributed in the crystaline rocks and hence the water entering the sea from streams draining such mineralized regions would be abnormally rich in the salts of these metals, which might result in the location of ore deposits at these points.

The only direct evidence favoring it is the fact that the structural basins in which the ores now occur are suggestive in shape of embayments at the mouths of streams or drowned river valleys. The presence within them and not generally elsewhere of considerable amounts of mechanical sediment deposited during a general period of base leveling is, farthermore, suggestive of nearness to rivers.[1]

Under "Local Abundance of Organic Matter" is emphasized the statement of Chamberlin that if structural basins existed at the top of the Platteville limestone during the time in which the oil rock was being formed they would catch most of the organic matter deposited and that the ores show a close relation to these basins.

Under "Locally Peculiar Organic Matter, Leading to Particular Efficiency in Producing Deposition" is given a table showing the relative reducing powers of various elements and compounds of which CH_4 ranks second only to hydrogen. An analysis[2] of the oil rock is given which shows it to be capable of giving off 57 volumes of gas which approximates CH_4 in composition.

Bain thus accounts for the irregularities in the lateral distribution of the ores and their apparent relation to the oil rock basins as being in a large part due to unequal deposition because of the accumulation of the oil rock in these basins; and the localization of the ores in this district to the peculiar composition and precipitating power of the oil rock and its decomposition products.

So far no objections have been raised to the conclusion reached by Whitney that the ores were derived from the crystalline rocks constituting the land areas to the northeast and precipitated from the sea with the sediments by the reducing action of organic matter. Chamberlin, by attributing the reducing agent to vege-

[1] Bain, H. Foster, "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey, No. 294, p. 133.

[2] Bain, H. Foster, "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey, No. 294, p. 26.

table decay and in particular to that contained in the oil rock, has an agent which is confined to these formations and the general mining district. His postulation of a sargasso sea is purely theoretical and founded upon insufficient data. His attempt to explain the localization of the deposits of Missouri and other states by this same sea seems entirely unwarranted, as these deposits occur in different formations, ranging in age from Cambrian to Carboniferous. His conception that the vertical distribution of the ores is due to their having been precipitated from the Ordovician sea at different times, the lead in the upper and the zinc and iron in the lower portion of the Galena limestone, is apparently based upon the lone fact that lead ore is usually found above the zinc and iron. While it is a fact that in a given section the galena usually occurs above the sphalerite, the lead ore is characteristically near the surface and above the water table and the zinc ore at a lower level, below the water table, so that these deposits bear a relation to the surface and water table rather than to any horizon within the Galena dolomite.

To Winslow's conclusion that the ores have been derived from the erosion of younger formations above, it seems to have been thought sufficient to call attention to the impervious character of the Maquoketa shale which directly overlies the ore-bearing formation. While this impervious character of the shale might prevent the ore from being derived from any formation above it, it would not prevent the ores from being derived from the Maquoketa shale itself, a fact which seems to have been entirely overlooked.

In the artesian theory of origin as proposed by Van Hise, the chemistry of the solution of the ores under oxidizing conditions, their later transportation through such a long distance by solutions which must become reducing and alkaline in nature, and their precipitation on encountering surface conditions, does not seem to agree with known chemical laws. Also, the ore deposits do not seem to show any such relation as might be taken to indicate the places where the shales were first eroded.

The possibility of some of the disseminated ore deposits hav-

ing been formed in their present condition by direct precipitation from the sea as proposed by Leith, is not in accord with the field evidence. Such deposits would consist of disseminated ore, a class of ore which is practically lacking in this district. In fact is seems safe to say that 97 per cent. of the ore mined in this district comes from openings such as fractures or bedding planes more or less enlarged by solution.

The theories of origin of the ores as advanced by Whitney, Chamberlin, Van Hise and Davis, which appeal to ascending or laterally moving solutions, and especially those of Chamberlin, Davis and Leith, postulating the precipitation of the ores from the Ordovician sea by the organic matter of the oil rock, are open to many of the objections which have been raised to the so-called "Galena-oil rock theory" as advanced by Bain and Grant. Because of the detail with which this theory has been given and its general acceptance in the mining district, the objections to it are given in more detail.

During the four seasons that the author has spent in this district, a number of points have been noticed that do not seem to be satisfactorily explained by the conditions postulated in this theory. These are briefly outlined below.

1. It is impossible to prove that any lead and zinc compounds ever existed as original minerals in the Galena limestone of this region, and, therefore, that this is an ample source. A series of nine analyses[1] is given to show the general presence of lead and zinc in all limestones; of these, all show the presence of small amounts of lead and six show zinc in the fourth decimal place, but they have all been subjected to the action of surface waters and it is impossible to say that all or any part of these metals has not been introduced from some formation above.

2. The Galena-oil rock theory does not explain the presence of large crystals of galena, "cog mineral," found in the "openings" in the Dubuque and Elizabeth districts. It cannot be supposed that water passing through the small pores of the

[1] Bain, H. F., "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey, No. 294, p. 130.

limestone and dissolving the ore, as postulated by this theory, could be other than alkaline or neutral and Buckley and Buehler[1] have shown that lead, zinc and iron sulphides precipitated from neutral solutions, lead and zinc sulphides from alkaline solutions, by neutralization, dilution or by H_2S are thrown down in an intimate mixture. Hence the formation of pure crystals of galena by this theory would involve a primary concentration of mixed sulphides and a later segregation either by the leaching out of the more soluble zinc and iron sulphides or by the solution of the whole and the reprecipitation of the lead by itself. The first would result in a residual of porous, iron stained galena and not in the well-crystallized lead sulphide so characteristic of these openings; while the occurrence of large amounts of this so-called "cog" mineral in the Dubuque and Elizabeth districts at practically the top of the Galena dolomite seems to preclude the second condition. Moreover, such lead ore as occurs lower in the formation and is known to be due to secondary concentration always occurs as small crystals.

3. The general order of occurrence of the three principal sulphides of the district from the surface downward is galena, blende and iron sulphide. As previously stated, the solutions which are supposed to circulate through the limestone and dissolve the minute particles or ore cannot be acid in nature, and hence the first concentration of the ores from such solutions would be an intimate mixture of them all, so that the Galena-oil rock theory must appeal to secondary concentration to explain the vertical distribution of the ores.

4. While the distribution of the oil rock (Fig. 1) corresponds somewhat closely to the area of the lead and zinc district and the thickest oil rock is found in the general neighborhood of the best mining districts, as Platteville and Hazle Green, Wis., the lateral distribution of the ores within the district does not correspond with the thickness of the oil rock. Thus whole townships in the vicinity of Lancaster are practically barren while others

[1] Buckley and Buehler, "Geology of the Granby District," Missouri Bureau of Geology and Mines, Vol. IV., p. 107.

near Highland, underlain by the less thickness of oil rock, are heavily mineralized. The thickness of the oil rock in the vicinities of Fennimore and Dodgeville is practically the same, yet but little ore has been found near Fennimore while Dodgeville has been a large producer. Bain[1] has the following to say on this point:

> It has been separately pointed out that thick oil rock has not been found away from the mines. Reasons have been given for believing that the reverse relation holds—namely, that ore deposits will not be found except in areas of thick oil rock. Since this is easily recognized in drill cuttings, it becomes a valuable supplementary guide in prospecting. It is important to have more data on this point in order to test the matter thoroughly. It may be frankly stated that at present the suggestion is based largely upon theory.

The recognized relation between the ore deposits and the oil rock basins has been explained by Bain as being due to thicker oil rock and hence greater original precipitation of the ores at these points. It should, however, be called to the reader's attention; first, that in some of the smaller folds, at least, the oil rock is also thicker on the crests of the folds than on the limbs; second, that there are many areas without ore deposits which are underlain by greater thicknesses of oil rock than that contained in many of the basins which do contain deposits and that there are many of these basins with thick oil rock but no ore; and third, that the flats and pitches and openings in general are confined largely to the oil rock basins, and that the ore-bearing solutions are controlled by these openings and the pitching, impervious oil rock troughs. So that the relation between the oil rock basins (thick oil rock) and the ore deposits is probably structural and not genetic.

5. Lead and zinc ores are found outside the district underlain by the oil rock. Such an occurrence is reported by Shaw[2] as follows:

[1] Bain, H. F., "Zinc and Lead Deposits of the Upper Mississippi Valley," Bull. U. S. Geol. Survey, No. 294, p. 144.

[2] Shaw, James, "Geological Survey of Illinois," Vol. V., p. 72, 1873.

Galena, or common lead ore, is and has been mined for, to some extent. There is an old crevice mine near the mouth of Yellow Creek, that has often engaged attention in years past, but no heavy amounts of mineral have ever been taken from it. From the quarries near Lena, 'chunks' as large as the fist have been taken. In the township of Oneco, a company of Freeport men prospected to a considerable extent, and obtained several hundred pounds of mineral. Near Weitzel's mill some 'prospecting' has been carried on. Along the banks of Yellow Creek some 'float mineral' has been picked up; and in almost any of the quarries, small bits of ore may be detected.

Thus while ore was not found in any great quantities here, it still shows that the conditions which caused the occurrence of the ores in the main district were effective at these points, and no trace of the oil rock could be found at Freeport, or about Rockton, Orangeville, Buena Vista and Sciota Mills to the northeast, north and northwest of Freeport.

North Buena Vista, Ia., marks the northwest limit of the oil rock which is here represented by a few knife-edge partings of shale which gives a slight oil rock odor but will not burn. But, ore in paying quantities has been mined west of Buena Vista, Turkey River and Guttenburg, Ia.

6. According to the Galena-oil rock theory the location of this district was due to one of three things—local abundance of the metals in the Ordovician sea at this point, local abundarice of reducing matter (oil rock), or peculiar precipitating power of the reducing matter (oil rock). Any or all of these being true, we have a right to expect that if any other formation was present in the Ordovician sea at this place and if it had an organic content equal to and as strongly reducing as that of the oil rock, it would result in the precipitation of an equal amount of ore. It will be later shown that there probably was another formation present which not only contained organic matter with a reducing power equal to that of the oil rock, but a much greater quantity of it.

7. If the localization of the ores is the result of the precipitating power of the oil rock acting in a sea of uniform or decreasing metallic content, this precipitation would take place the

most rapidly when the oil rock was first formed and the gases most abundant and free to escape, decreasing rapidly with time and with the accumulation of the superimposed Galena limestone. Therefore the original disseminated ore particles would not be scattered uniformly throughout the Galena limestone, but would be the most abundant at its base, decreasing rapidly in amount with the distance from the oil rock. No evidence of such a concentration has yet been found, in fact all evidence seems to point to the contrary. That such ore should be dissolved and concentrated at the top of the formation seems improbable, and drill records have so far failed to show the presence of ore deposits near the oil rock in the southern portions of the field, *i. e.*, the ores seem to bear a strong relation to the water table, rarely exceeding a depth of more than 100 feet below this level, and rising in the formation with its increase in thickness to the south. The ore shows but slight relation to the oil rock unless it comes within this zone, and then apparently not because of any particular effect of the oil rock upon the ore itself, but rather of the control exerted by the oil rock upon the water circulation and the formation of the flats and pitches in which the ore was deposited.

8. The ore deposits occur in general in openings which are due to solution along fractures, this, especially when the ore occurs as a coating on the walls, indicates that a large portion of the solution took place before the deposition of the ores. If the ores were derived from the wall rock it seems reasonable to suppose that the start of seapage from the walls, and therefore deposition of the ores, would be contemporaneous with that of solution and that it would continue until the wall rock was depleted of its metals.

9. The ore deposits occur in general in solution openings, directly connected with the surface and which, without doubt, have been formed by direct meteoric solutions. The presence of shells within the ore shows that, in places at least, solution of the dolomite has been contemporaneous with the deposition of the ores. But solutions which have passed through the small

pores of the Galena dolomite for a considerable distance, as postulated by the Galena-oil rock theory, would be saturated with lime and incapable of farther solution of this material, so that they could neither have formed the openings in which the ore occurs nor have enlarged them.

THE RELATION OF TEXTURE TO THE COMPOSITION OF COAL.

FRANK F. GROUT.

INTRODUCTION.

In discussing the differences in composition and origin of various coals, men have usually considered the composition of the seam *in toto* as distinct from some other seam. Often, the several benches of a seam have been separately tested, and in a few cases, mostly over thirty years ago, particular textures have been selected from a seam, for analysis; but in these latter cases a comparison with other textures of the same seam is seldom possible from the published data. McCreath[1] reported proximate analyses for several textures from one mine, but found little variation, and it is possible that this physical analysis really shows less difference in the textures than the ultimate analysis. Moreover, it is widely accepted, that the four or five textures commonly seen in a lump of coal do vary in composition and value. Miners and firemen often have some idea of the value of each as fuel from its behavior in the fire. Commercial sampling has been widely discussed on account of the variable distribution of ash, but other variations are often implied. This paper adds a set of analyses and gives some discussion and analyses of other material for comparison.

FIELD NOTES AND ANALYSES.

The writer visited some coal mines during the summer of 1910 for the Colorado Geological Survey, and at the Gorham Mine, Marshall, Colo., found the material of a single seam, so varied and so sharply separable that some attention was given to the selection of samples for analysis.

[1] 2d Geol. Survey of Penna., Vol. MM, pp. 80–81.

The coal is of the Lower Laramie formation, and has been known as black lignite, but since the recent change in naming low grade coals, may be called sub-bituminous. It is black and massive except for bedding planes. Joints are poorly developed. The coal slacks by irregular fracturing, and the slacking may be quite serious after long standing in dry air. None of the samples gave coherent coke. The textures separated and their occurrence, composition and general characters follow (see Figs. 58, 59 and 60 for the appearance of these textures).

TABLE I.

ANALYSES OF SELECTED PARTS OF A COAL SEAM. (ALL AIR-DRIED.)

	1	2	2(a)	3	4	5	6	7
Moisture	13.78	9.02	7.44	7.55	12.03	0.00	1.77	5.64
Volatile matter	41.37	37.20	36.32	32.45	43 54	98.28	11.03	23.16
Fixed carbon	41.91	38.81	37.27	57.18	41.96	1.15	9.40	10.28
Ash	2.95	14.97	18.97	2.82	2.47	0.57	77.80	60.94
Sulphur	0.42	0.31	0.27	0.17	0.16	0.00	0.04	0.09
Carbon	61.01	47.41	42.88	71.45	63.04	79.29	14 67	21.57
Hydrogen	4.91	4.27	4.05	4.28	5.21	10.28	1.01	2.16
Oxygen	29.79	32.16	32.96	20.49	28.24	9.86	6.48	14.78
Nitrogen	0.92	0.88	0 87	0.79	0 88	0.00	trace	0.46

1. Glance coal, bright, lustrous, the "gas coal" of eastern states. 2. Hard dull coal, resembling splint. Not entirely free from inclusions of glance coal. 2(*a*). Calculated for dull coal, assuming that sample 2 contained 25 per cent. glance coal. Peculiarities are accentuated. 3. Mineral Charcoal. "Mother-of-coal." 4. Cannel-like coal. 5. Resin. Very small amount available for tests. 6. Bone-coal. Siliceous peculiar type. 7. Roof slate.

The first two types make up most of the coal. Their relationship is that common to most coal beds, an alternation of thin irregular bands. However, in large lumps, it seems evident that the dull coal is the matrix, and the glance coal layers are flattened fragments once suspended in this matrix. It is difficult to find thick layers of the dull coal without numerous small inclusions of the glance coal, besides the larger fragments which gave the appearance of layers. A woody structure is often visible in the large fragments of glance coal, but is usually concealed by the highly conchoidal fracture. This woody structure and the lenticular cross section which is also common in the glance coal, sug-

gest an origin from some tree trunk, greatly flattened and impregnated. This type of occurrence of fragments, layers and

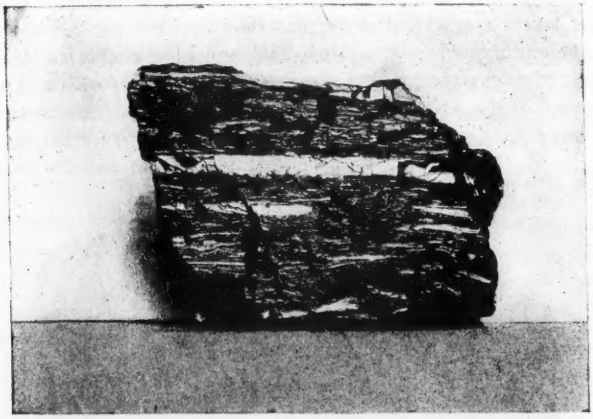


FIG. 58. Common alternation of bright and dull coal.

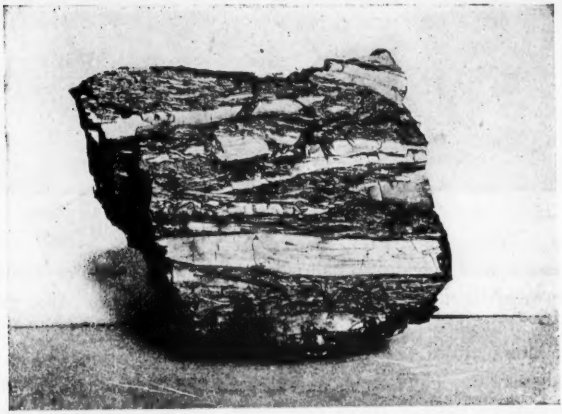


FIG. 59. The bright coal showing woody structure.

lenses, here seen in lignite, is quite the same as is seen in bituminous and anthracite coal.

The mineral charcoal also occurs as in other types of coal. The layers are seldom more than half an inch thick, and are numerous only when very thin. The cannel-like coal resembles a layer of glance coal, with a somewhat more waxy luster and an absence of the woody markings. The layer was thicker than is common in glance coal. The so-called rosin varies from light

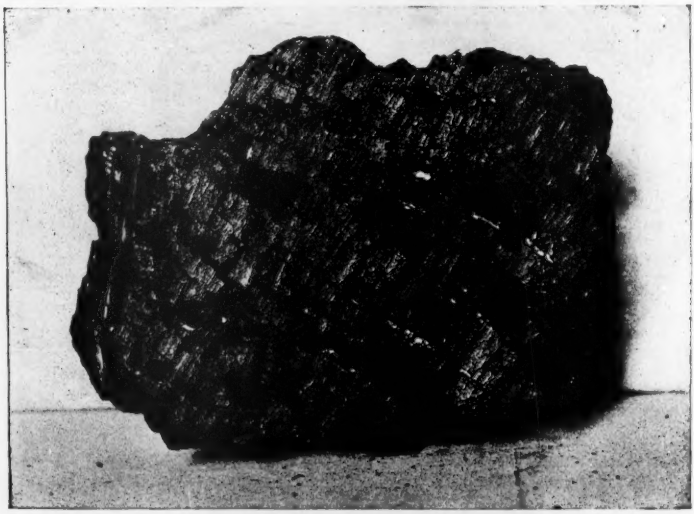


FIG. 60. Mineral charcoal.

yellow to dark brown, and shows neither woody nor crystalline texture. Although sometimes in the form of drops, like gum from a tree, it is much more often spread in thin sheets along some irregular joints. It occurs in the roof slates as well as in the main coal. The bone coal here spoken of, is not exactly the bone coal of eastern states, but seems to be a partly silicified, partly carbonized log, still retaining a pronounced woody ap-

pearance, especially where weathered. The roof slates are dark and carbonaceous, with some few particles of glance coal included.

DISCUSSION.

At first glance these analyses make two things prominent, viz., that the last three analyses represent material not strictly comparable with the others, and that the first four analyses, which represent the main coal mined, vary most decidedly, not only in impurities but in the essential fuel constituents. The resin proves to be worthy of a study by itself, as its composition differs from coal as widely as its occurrence. The bone coal and slate have so much ash that the actual percentages of the organic materials have little significance. Even a calculation of the ratios, independently of the impurities, is not satisfactory, because the inorganic material must have contained some hydrous minerals, like clay, which contributed to the volatile matter and hydrogen to an unknown extent. There remain four textural varieties for strict comparison.

The analyses given are thought to be typical of the variation of composition with texture. It is easily found, however, that the variation is not always the same. Tables III. and IV. show that the relation of the composition of mineral charcoal to that of its surroundings is not at all uniform. One can easily see why two samples from a single mine may disagree, when one remembers that the proportion of each constituent varies in short distances. It is not well to conclude with Messrs. Parr and Wheeler, or Bement[1] that the hydrocarbon of a seam of coal is even approximately constant. The idea is not a new one. Percy's "Metallurgy, Fuels," page 292, in 1875 says: "While the inorganic constituents of a lump of coal may be unequally distributed, there is reason for believing that generally the composition of the organic matter of that lump is not subject to the same variation." While the formulas given by Parr and Bement may save some time in technical work on mine production, the analyses here given indi-

[1] "An Initial Coal Substance Having a Constant Thermal Value," Illinois Geol. Survey, Bul. 8, pp. 154–166, and Bul. 16, pp. 211–213.

cate that the fundamental idea is not correct. A test of the textures in Illinois coals should be convincing, as they are said to be largely but not uniformly supplied with mineral charcoal.

It is instructive to apply to the analyses above the various methods of classification suggested for coal. The fuel ratios are very near 1, except in case of mineral charcoal, 1.8. The C:H ratio as proposed by Campbell,[1] shows a range from lignite to the highest grade of bituminous coal. The same ratio calculated without the hydrogen of the water, varies from less than 15 to nearly 21. The writer's method of classification[2] uses the per cents of carbon and of fixed carbon in the ash- and water-free coal. This also shows a variation in the samples, from low-grade lignite to high-grade bituminous coal in this one seam. The differences are very striking.

The glance coal is high-grade lignite, and the dull matrix has too little carbon to be classed above peat or wood, in most systems, but in other ways is like lignite. The cannel-like sample is a lignite closely approaching the cannel group in composition. Distinct from all these is the mineral charcoal which is high grade bituminous. It is exceptional in all its ratios. The data for these comparisons may be tabulated.

TABLE II.

RATIOS CALCULATED FROM FOUR ANALYSES OF TABLE I.

	1	2	2(a)	3	4
Fixed carbon.					
Volatile matter	1.0	1.0	1.0	1.8	0.9
Carbon.					
Hydrogen in dry coal	18	14.5	13	21	16
Total carbon in "pure coal"	73.27	62.39	58.15	80.00	74.60
Fixed carbon in "pure coal"	50.33	50.04	50.46	64.53	48.75

THE COALIFICATION PROCESS.

Dr. David White, in discussing "Some Problems in the Formation of Coal," suggests that chemical work may throw some light on several obscure points.[3] It may be well to quote some

[1] U. S. G. S., Prof. Paper 48, Pt. I., p. 172.
[2] This journal, Vol. 2, p. 240, and Vol. 4, p. 657.
[3] This journal, Vol. 3, p. 303.

of his outline from the standpoint of a paleobotanist, and see how these analyses are related to it.

In the process of putrefaction, as described by Renault, the thinner walled cells are first effectually corroded, while at the same time the protoplasmic contents, filled with bacilli, become at first yellowish and later gradually brownish and turbid, slowly coalescing and becoming flocculent as the disintegration and destruction of the intervening cell walls progress. If arrested in an early stage the accumulating more or less pasty mass may remain brown with a very large content of undestroyed tissues; but if uninterrupted the process goes on until all the softer tissues are disintegrated and decomposed, leaving only the most enduring and indestructible parts, such as fragments of cuticle and seeds, or spore envelopes, immersed in a dark subgelatinous plastic or liquid mass, the fundamental jelly . . . a profoundly important product. This fundamental matter, of probably variable constitution and contents, forms the amorphous ground mass of the coal. It is the binder that cements the fregments of undisintegrated tissues as well as the included sediments. Ordinarily it not only envelopes the undestroyed woody matter but it infiltrates the surviving tissues to a greater or less extent. The larger stems that have settled into the asceptic coal-forming mass, or the larger fragments that have escaped disintegration are usually more or less completely infiltrated with this fundamental jelly. Where the impregnation is complete we find dense, glossy, or jetty and shining (according to the progress of coalification) woody section with conchoidal fracture. . . . In many instances the impregnation has been imperfect; in some examples the impregnation intergrades to a charcoal or "mother of coal." . . . Most paleobotanists and chemists still treat the so-called 'mother of coal' which forms layers in so many of our bituminous coals, as the remains of cinders, the work of forest fires. With this interpretation the writer disagrees. The phenomena of vegetable decay and accumulation as witnessed notably in peat bogs at the present day appear to justify the belief that these fragments of wood owe their form and condition more or less directly either to a partial dry rot before immersion or, as seems more probable, to a temporary exposure of the coal forming accumulation to the air, the results being largely the same.

Cannel and bog head coals are described in this same paper as forming by similar processes acting on spores and algae instead of the more common plant tissues.

The chemical changes during coalification are complex, and very imperfectly understood, but the general result as plant tissue becomes bituminous coal is a decrease of oxygen, with an approximate balance in the losses of other elements.[1] With this outline of the process and chemical effect, we may compare the analyses point by point.

ORIGIN OF THE TEXTURES.

The Glance Coal.—This is commonly known by the miners to be lower in ash than the dull coal or coal jelly in which it is suspended. Hence the usual opinion that bright lustrous coal is desirable. A most important characteristic is the C:H ratio. The origin of such material by impregnation of woody tissue with the fundamental coal jelly involves a discussion of the dull coal first.

The Dull Coal.—This differs from glance coal most notably in ash. Otherwise the proximate analyses are much more alike than would be expected from a glance at the ultimate composition. The high ash of the fundamental coal jelly might be expected in view of the origin suggested inasmuch as sediments and all inorganic impurities would be suspended in it, but could not easily penetrate a solid piece of wood. As the sample analysed was not entirely free from glance coal, the ash content of the fundamental matter may be even higher than that reported. If one fourth of the sample is assumed to be glance coal, a calculation of the actual ground mass, shown in column *2a*, accentuates the peculiarities. Note that the C:H ratio is lower than in any other sample. None of the suggestions regarding origin, offer a satisfactory explanation of this low ratio. In the process of change from sphagnum moss to the jelly like mass of peat, the ratio C:H increases; but in the coal, the jelly has a lower ratio than the woody fragments. The theory of impregnation of the glance coal fragments with material of the fundamental jelly, must account for the fact that the fundamental jelly has the lowest of C:H ratios and yet when the source of glance coal is impregnated

[1] Grout, *Jour. Am. Chem. Soc.*, Vol. 29, p. 1497.

with this jelly, it has a ratio above the average. It is possible that the impregnated material may have been extremely low in hydrogen, like mineral charcoal; or, the material passing from this fundamental jelly into these wood fragments may differ from the jelly left behind; but however it happened, the process is not at all clear.

The Cannel-like Sample did not show a very pronounced difference from the glance coal. Hydrogen was only slightly higher. The general relation between the composition of cannel and that of other coal is well known, and in this case Dr. White's paper includes some analytical data. The materials he selected were the extreme types, however, and data are not common showing the differences in one locality. Following the plan of distinction of coals of a single seam, reference may here be made to some analyses made for the Illinois Geological Survey, showing cannel and other coal from seam number five, at the Mathieson, Hegler Zinc Company's mine at La Salle, Illinois.[1]

	Water.	Vol. Mat.	Fixed C.	Ash.	S[2]	C	H	(O+N)	C : H
Cannel.....	6.45	41.15	30.56	21.84	10.18	44.93	5.39	25.76	9.6
Average.....	13.13	37.67	38.60	10.60	2.93	59.20	5.78	21.49	13.7

These were thought to be more typical of the cannel variation than were the samples from Colorado. The Illinois cannel formed a lens, 100 to 200 ft. across and about a foot thick, at the top of the main coal. The high sulphur was a surprise, as the appearance had not suggested it. The analyses add no points to the usual conclusion as to origin.

The So-called Resin has the color and luster of resin and about the same tenacity. It melts at 175° to 180° C., to such an extent that lumps about one sixteenth of an inch thick spread and run together. It is soluble in the common organic solvents, ether, chloroform, benzol, xylol, and carbon disulphide—much more completely soluble than most fossil resins as described under "retinite" in Dana's "System of Mineralogy." From the ether

[1] Ill. Geol. Survey, Bul. 4, p. 198, and Bul. 16, p. 215.

[2] Allowance is made for high sulphur in calculating oxygen.

solution alcohol forms a white flocculent precipitate. The supply of material was too small to allow accurate tests for succinic acid, a constituent of ambers and resins. The ultimate composition is not far from that found in other similar material and is not conclusive as to its origin. Much more important is the observation of its occurrence in vertical joints. It seems clearly secondary and may have reached its present state and position as a sort of exudation from the solid matter during or subsequent to the main coalification process. If not secondary it probably formed from

FIG. 61. Forest wood superficially charred.

a sort of gum, as is usually supposed. The literature referring to such resin indicates that it is characteristic of brown coals, rather than black ones like this.

The Mineral Charcoal has already been noted as exceptional in nearly every respect. Many years ago, Bischoff, in his "Physical and Chemical Geology," reported structures in the charcoal resembling araucarias and calamites, and rarely others. Professor Harkness noted[1] also a more granular variety than is typical,

[1] Ed. *New Phil. Jour.*, January, 1885.

which he referred to sigillarias. Both seemed to conclude that charred wood was the source of the textural variety. To make the study reasonably complete several analyses have been compiled from the literature, and, as far as possible, the charcoal analyses are paired with those of normal coal from the same seam. Rowney gave several ultimate analyses of Scottish coal, and McCreath proximate tests from Pennsylvania.

TABLE III.

ULTIMATE ANALYSES OF MINERAL CHARCOAL AND OF AVERAGE COALS FROM THE SAME SEAMS. (*a*) CHARCOAL SAMPLES. (*b*) AVERAGES. ALL DRIED.

	C	H	O	N	S	Ash	C : H
1. (*a*)	77.27	3.74	14.91	.85	.18	3.05	21
2. (*a*)	76–82	3.5–3	20–15	—	—	—	24
3. (*a*)	82.97	3 34	6.84	.75	—	6.08	24
4. (*a*)	72.74	2.34	5 83		—	19.08	31
5. (*a*)	73.42	2.04	8.25		—	15.38	25
5. (*b*)	76.08	5 31	15 42		1.23	1.96	14
6. (*a*)	74.71	2.74	7.67		—	14.86	27
6. (*b*)	80.63	5.16	11.94		84	1.43	15
7. (*a*)	81.17	3.84	14.98				21
7. (*b*)	80.93	5.21	13.86				15

1. Marshall, Colo., from a lignite, F. F. Grout, analyst. 2. Saxony. Range for several specimens, Professor Stein, analyst, quoted by Gruner in *Annales des Mines*, s. 7, (1873), p. 169 et seq. 3, 4, 5, 6 and 7. Analyses by Rowney, published in *Ed. New Phil. Jour.*, Vol. II. (1855), p. 141. 3. Glasgow household coal. 4. Stonelaws coal. 5. Ayrshire coal. 6. Fifeshire, Elgin Colliery, splint coal bed. 7. Fifeshire, Elgin Colliery, Five-foot seam.

These analyses may form the basis of some generalizations. It has been said that the porosity of the charcoal made it especially subject to impregnation with pyrite, but the few cases in which sulphur has been determined show no such tendency. All Rowney's work and the average of McCreath's, show a tendency toward high ash in mineral charcoal, but Table I. shows a much greater tendency in the dull hard coal—the fundamental jelly. The ash in mineral charcoal may be much lower than that of other textural varieties.

TABLE IV.

PROXIMATE ANALYSES OF MINERAL CHARCOAL AND AVERAGE COALS FROM THE SAME SEAMS. (*a*) CHARCOAL SAMPLES. (*b*) AVERAGE SAMPLES.

	Water.	Volatile Matter.	Fixed Carbon.	Sulphur.	Ash.	Fuel Ratio.
1. (*a*)	7.55	32.45	57.18	.17	2.82	1.8
2. (*a*)	1.17	19.77	72.13	—	6.93	3.6
2. (*b*)	1.94	39.26	55.83	.73	2.24	1.4
3. (*a*)	.75	20.36	71.07	—	7.82	3.5
3. (*b*)	1.37	37.80	54.46	1.59	4 78	1.5
4. (*a*)	2.39	12.40	75.34	—	9 87	6.1
4. (*b*)	1.68	34.97	57.00	.67	5.67	1.7
5. (*a*)	.52	11.36	82.94	—	5 18	7.3
5. (*b*)	1.18	26 50	56.70	.67	14.97[1]	1.8
6. (*a*)	.52	14.32	64.03	—	21.13	4.5
6. (*b*)	1.04	28.01	49 24	4 50	17.21	1.8
7. (*a*)	.55	9.92	81 37	—	8.16	8.2
7. (*b*)	.85	16.85	69.58	2 59	10.13	4.1
8. (*a*)	.85	8.36	87.64	—	3.15	10.5
8. (*b*)	1.19	20.76	71.70	1.02	5.33	3.5
9. (*a*)	.57	20.98	70.37	—	8.08	3 3
9. (*b*)	.77	17.11	70.74	.78	10 60	4.1
10. (*a*)	.85	10.49	84 01	—	4.65	8.0
10. (*b*)	.94	17.85	72.15	.67	8.39	4.0
11. (*a*)	1.41	6.40	87.11	—	5.08	13.6
11. (*b*)	1.84	9.83	76.79	.65	10.89	7.8
12. (*a*)	1.22	8.60	82 56	—	7.62	9 6
12. (*b*)	2.10	8.04	80 43	.60	8.83	10.0

1. Marshall, Colo., Gorham Mine, F. F. Grout, analyst. 2–12. Analyses by McCreath, Second Geol. Survey of Penna., Vol. MM, pp. 1–107. 2. Lawrence Co., Pa. Miller's bank. Upper bench, Brush Creek coal. 3. Beaver Co., Pa. Todd's bank. Upper bench. Upper Freeport coal. 4. Indiana Co., Pa. George's bank. Pittsburg coal. 5. Indiana Co., Pa. Hazlett's bank. Upper bench. Upper Freeport coal. 6. Blair Co., Pa. Glen White Coal Co. Lower bench, Clarion coal. 7. Somerset Co., Pa. Wigle's Mine, Upper Kittaning coal. 8. Arnot, Tiogo Co., Pa. Upper bench, Clarion Coal. 9. Barclay Bradford Co., Pa. Clarion coal. 10. Barclay, Bradford Co., Pa. Middle bench, Clarion coal. 11. Bernice, Sullivan Co., Pa. Upper bench, Clarion coal (semi-anthracite). 12. Dauphin Co., Pa. Lykens Valley anthracite.

It would seem from the descriptions given with the quoted analyses, that most of the coal beds yielding charcoal were bituminous, with a few cases of anthracite. The new one now presented is the only one from lignite or sub-bituminous coal. Assuming that the new analysis is typical of the charcoal of lignites, there appears to be a gradation from lignite charcoal to

[1] Total was not 100 per cent. in original.

anthracite charcoal, in the same direction as the gradation from lignite to anthracite. The writer's estimate from the data is as follows:

TABLE V.

VARIATION IN THE COMPOSITION OF MINERAL CHARCOAL WITH THE NATURE OF THE ENCLOSING COAL.

Source.	Water.	Vol. Mat.	Fixed C.	Ash.	Sulph.	Carbon.	Hydr.	Oxy.	Nitrog.
Lignite	7.55	32.45	57.18	2.82	.17	77.24	3.74	14.91	.85
Bituminous	1.00	14.30	76.50	8.30	—	79.30	3.24	9.31	.85
Anthracite	1.00	7.50	84.90	6.00	—	?	?	?	?

While the change in charcoal is essentially similar in kind to the change in the surrounding coal, it is clear that the alteration tends to produce the same end product as far as composition is

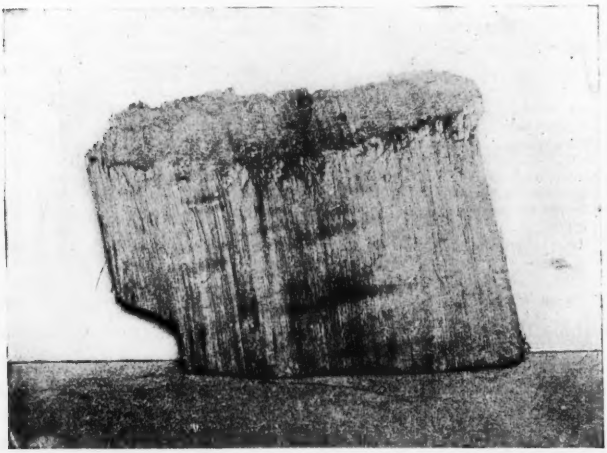


FIG. 62. Fresh wood of the same tree as Fig. 61.

concerned. Though the charcoal from lignite differs widely from lignite, the charcoal from anthracite is much like anthracite. It seems reasonable to think that the chemical difference was in existence when the coalification process began, and disappeared grad-

ually as the process was completed. There is some question as to the cause of the difference before the beginning of the main process. In the above quotation, Dr. David White favors the idea of a process of dry rot or other sub-aerial decay, rather than charring. The writer has found very few and indefinite references to the composition of decayed wood, and none to that naturally charred, and has therefore added some work in the hope of obtaining material for a preliminary conclusion as to the source of mineral charcoal. Table VI. contains a summary of the available data. The analyses of oak are averages from Percy's Metallurgy; those of sphagnum and peat from Ries's Economic Geology; the rest are added by the writer. All are recast to an ash- and water-free basis.

TABLE VI.

ANALYSES OF DECAYED AND CHARRED PLANT TISSUE.

	Carbon.	Hydrogen.	Oxygen and Nitrogen.	C·H	C:O
Oak wood	50.24	6.08	43.65	8	1.2
Decayed oak	51.17	5.66	43.17	9	1.2
Sphagnum	49.88	6.54	43.58	7	1.1
Peat	59.70	5.70	34.60	10	1.7
Cottonwood	46.26	5.96	47.88	8	1.0
Dry rotted cottonwood	53.01	5.82	41.18	9	1.2
Charred cottonwood	71.23	3.33	19.44	23	4.0
Lignite	68.38	4.18	27.44	16	2.5
Mineral charcoal	79.87	3.84	16.29	21	4.9

These various tests agree in showing that the change of composition during decay of wood are slight, and not at all such as could give the difference observed between lignite and mineral charcoal. The process of peat formation has somewhat more effect than dry rot in this way, but even here the change in ratio C:O is only from 1.1 to 1.7, while the lignite charcoal ratio is nearly double that for lignite. If dry rot was the effective agent, it must be that the effect is not one of composition, but rather that new compounds are formed, with about the same proportion of elements—these compounds, however, being capable of radically different behavior in subsequent alteration.

It may be worthy of note that the charring caused by forest

fires is by no means as complete as that producing fuel charcoal. The texts on metallurgy give the following:

	Carbon.	Hydrogen.	Oxygen and Nitrogen.	Ash.
Beech wood.....	48.11	6.08	45.24	0.57
Beech charcoal...	87 93	2.52	1.50	8.05

Since these analyses do not confirm the paleobotanist's conclusion as to the origin of mineral charcoal, it may be well to state at once, that it does not in any way affect the evidence on which the conclusion is based, viz., a study of the structure and association of the type, and of modern vegetable accumulation

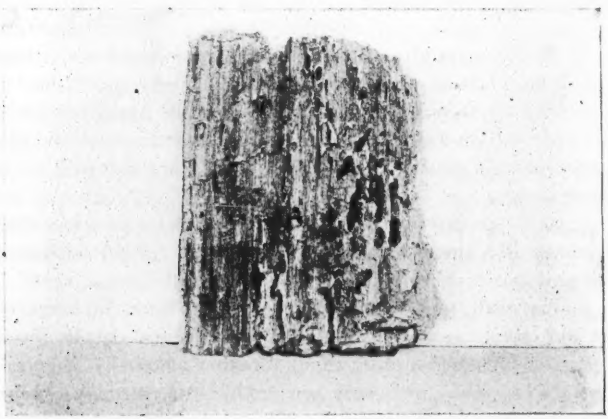


FIG. 63. Dry rotted wood of the same tree as Fig. 62.

and decay. More evidence should be gathered on these points, however. The evidences that the wood was charred may be stated here together: (1) The appearance is that of charcoal (see Figs. 60 and 61). (2) There can be little question that fires must occasionally have swept the forests of the coal-forming period.[1] (3) The consistency of dry rotted wood makes it less

[1] U. S. D. A. Forest Service, Bul. 79, p. 8. Dr. F. E. Clements reports having known of five or six fires in a small area *in a single summer, started by lightning.*

likely to be preserved as a fragment in the "coal jelly," than to become macerated and a part of that jelly; but charred wood is more firm and the solid wood often left within may help protect it. (4) It is uncertain whether dry rot makes bacterial action more or less easy, but the charred wood is almost proof against such action. (5) Chemical analyses show a much closer relationship between charred wood and mineral charcoal than between decayed wood and mineral charcoal. (6) In present day forests it often happens that a tree of great thickness is almost entirely dry rotted, but such a mass of fiber should yield a much thicker layer of mineral charcoal than is actually found commonly in the coal.

SUMMARY.

1. Analyses are given of seven samples selected from a single coal seam on the basis of varying texture.

2. The variation is so great, not only in the impurities but in the hydrocarbon, that it is not safe to assume an initial coal substance having even an approximately constant composition or thermal value.

3. As the proportion of the several constituents varies in short distances in a single seam, the analyses bear further witness to the need of a careful study of mine sampling.

4. The analyses have considerable bearing upon the origin of these textural varieties. A summary of chemical data is given, especially for mineral charcoal, or "mother of coal." The analyses are compared with some new analyses of naturally charred wood and lead to the conclusion that mineral charcoal is formed by forest fires rather than by a sort of decay, which process is indicated by a paleobotanical study. The analyses confirm the popular idea, rather than the reverse.

THE EVERGREEN COPPER MINE, COLORADO.[1]

EDSON S. BASTIN AND J. M. HILL.

Introduction.—The Evergreen mine, in Gilpin County, Colo., is situated in the valley of Pine Creek about half a mile south of the little mining camp of Apex. In a region characterized by typical fissure veins whose principal values are in gold and silver, it stands unique because its principal values are in copper and because the ore minerals are not in a fissure vein but occur disseminated through an igneous rock. Its unusual features attracted the attention of Etienne Ritter[2] who described the mine in an interesting article published in 1907 in which he showed that the copper sulphides crystallized contemporaneously with the other minerals of the rock.

The observations which follow were made by the writers in the fall of 1910. They contain some new data on the mineralogy of the ores and in the writers' opinions indicate an unusual origin through the endomorphic effects of contact metamorphism.

Development.—The Evergreen mine was first worked in the early eighties but its modern development began with its acquisition by the present company in 1904. The mine is developed by a vertical shaft with levels at 60, 150 and 200 feet. The 60-foot level was inaccessible. The length of the drifts on the 150- and 200-foot levels are respectively 130 and 490 feet. About 50 feet north of the shaft is the mouth of a tunnel about 565 feet long. The general trend of both drifts and tunnel is somewhat west of north. Mining has been largely exploratory; there has been no stoping on the 200-foot level but the drift at the 150-foot level has been stoped for 50 feet of its length, locally to a height of 15 feet. In the tunnel very little stoping has been done except at one point about 120 feet from the mouth where a large chamber-stope

[1] Published with the permission of the Director of the U. S. Geological Survey.

[2] *Trans. Am. Inst. Min. Eng.*, Vol. 38, 1907, pp. 751–765.

about 40 feet long, 30 feet wide and from 2 to 12 feet high has been excavated.

The plant which is operated by steam power consists of shaft house and mill. The shaft is equipped with bucket hoist. In the mill, which has a capacity of about 60 tons in 24 hours, the ore, after crushing, goes to a conical settling tank and then to Richards pulsating jigs and Card tables. The ore must be hauled by team eight miles to Black Hawk.

Geological Relations.—The prevailing rocks at the Evergreen mine are Idaho Springs schists[1] injected by small amounts of granite-pegmatite. The schists are probably meta-sedimentary, the prevalent type being a rather fine-grained quartz-biotite schist. Lime-silicate phases which probably represent metamorphosed calcareous beds occur within the formation, although not noted in the immediate vicinity of this mine. Both schist and pegmatite have been intruded by dikes of light-gray rock which are probably offshoots from the large stock of monzonite outcropping less than one-half mile north and east of the mine (see Fig. 64). The ore minerals, which are chalcopyrite and bornite, are largely confined to the dikes and to the igneous breccias formed by the shattering of the wall-rocks during the intrusion of the dikes. The mineralization is commonly greatest in the breccias but in these the sulphides are confined to the igneous matrix and are wholly absent from the contained fragments of wall-rock. The latter are always angular and show little evidence of metamorphism by the dikes. As a consequence of this distribution of the ore the development commonly follows the dikes though some exploratory workings are mainly in schist. The north drift on the 200-foot level follows a dike for about 250 feet. This dike is 1 to 1½ feet wide, strikes on the average about N. 25° W., and dips at about 50° to the east. The drift on the 150-foot level follows what may be the same dike for 130 feet. On this level the dike rock has intensely brecciated its host and the igneous breccia is in places 4 feet wide. In the tunnel dikes are encountered at several places. They are frequently interrupted by faults

[1] Spurr, Garrey, and Ball, "Geology of the Georgetown Quadrangle, Colorado," Prof. Paper U. S. Geol. Survey, No. 63, 1908, p. 37.

and their exact relationships to each other are thus rendered uncertain. The narrower dikes exposed in this tunnel are 2 to 3 feet wide, while larger masses exceed the width of the tunnel by an indeterminate amount.

Petrology of the Ore-bearing Dikes.—The dike rocks exposed in various portions of this mine are in general of similar character. They are light-gray rocks, in places sub-porphyritic in

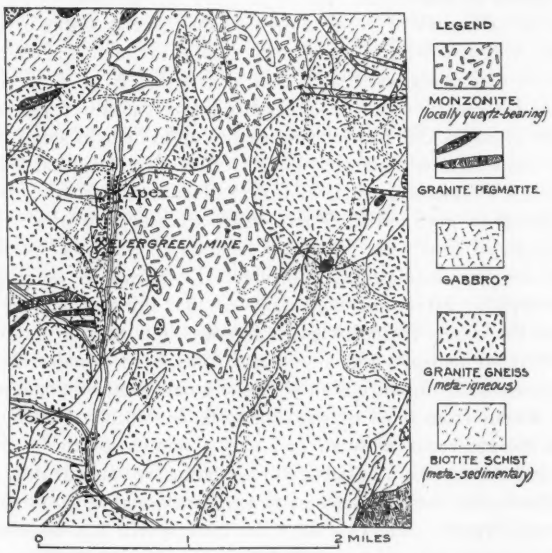


FIG. 64. Map showing general geological relations near the Evergreen Mine.

texture through the development of pink feldspar crystals above the average in size. The porphyritic phases to the unaided eye appear closely similar to the monzonite forming the neighboring stock but when studied microscopically important differences are observed. In a common type which is even grained a great abundance of minute colorless prisms is recognizable with the unaided eye. Under the microscope the subporphyritic phases

are found to be almost perfectly fresh, granular in texture, and composed dominantly of feldspar, augite and wollastonite. The feldspars are mainly of the orthoclase and microcline varieties finely (perthitically) intergrown with albite, and the grains are of all diameters up to about 5 mm. Occasionally there is a small crystal of plagioclase (oligoclase or andesine). Quartz in smaller grains is very abundant. The grass-green augite is nearly equal to quartz in abundance. Its crystals are seldom over 5 mm. long but in the matrix of some of the igneous breccias augite prisms 5 mm. wide and 8 mm. long occur. Wollastonite forms abundant prisms commonly less than 1 mm. in length. In portions of the dikes it is nearly equal to feldspar in amount and in a few specimens from the dump it formed needles up to 1 cm. in length. It is the white fibrous mineral so characteristic of certain hand specimens. Titanite usually showing crystal outlines, garnet crystals of irregular outline, and small zircons are accessory minerals. Small amounts of calcite are present occasionally. In some specimens they are plainly an alteration product of wollastonite, being pseudomorphous after the long prisms of that mineral but in other cases the calcite forms irregular masses showing sharp contacts with fresh feldspar and augite, and may be original. Opaque minerals with the exception of some small grains of magnetite are absent from most of the dike rock, but locally chalcopyrite and bornite occur in small and very irregular patches. These sulphides are present in particular abundance where the dike rock encloses abundant fragments of wall rock and thus forms an igneous breccia. The two sulphides chalcopyrite and bornite are contemporaneous and are irregularly intergrown with each other, and they are commonly accompanied by garnet, a mineral which is rare except in immediate proximity to these sulphides. The garnet and sulphides are unquestionably contemporaneous with the other minerals of the rock. They are in sharp contact with perfectly fresh individuals of all the principal constituents. In some places the bornite encloses augite and wollastonite. Needles of wollastonite also penetrate bornite. In other cases bornite is wholly enclosed by quartz. Sulphides occur enclosed between prisms of wollastonite.

The richest ore which has been produced at this mine was taken from a large chamber-stope about 120 feet from the mouth of the tunnel. The stope is near the surface and the geologic relations are much obscured by oxidation, but two distinct dikes are recognizable. Much of the ore from this stope is a breccia of angular gray quartz fragments in a matrix of dike rock. To the unaided eye the sulphides which are abundant appear to be confined to the dike rock matrix. Under the microscope this matrix shows no important differences from the ordinary dike rock of other parts of the mine. The quartz of the fragments enclosed in this matrix interlocks at its borders with the minerals of the matrix, indicating some recrystallization and welding at the time of the intrusion, but matrix and quartz fragments are very distinct when viewed in the hand specimen. In the slide the matrix is seen occasionally to send off small branches or stringers of bornite and feldspar into minute cracks which traverse a single quartz crystal or penetrate between two crystals of the fragments. The origin of the quartz which forms the fragments of this breccia is uncertain but it probably represents a quartzose phase of the pegmatite which is so abundantly associated with the Idaho Springs schists. That the large quartz masses do not represent coarse crystallizations of quartz within the dike rock is apparent from their commonly angular character, from the absence of comparably coarse crystallizations of the other dike minerals and from the great contrast in size (several inches as compared with 1 mm. or so) between the large quartz masses and the quartz of the matrix.[1]

[1] Mr. Ritter (*ibid.*, p. 751) gave to the dike-rock the name "Evergreenite." The long prisms of a colorless mineral were identified by him as enstatite or diallage. Their optical properties, however, identify them unquestionably as wollastonite. These properties may be summarized as follows: inclined extinction; index of refraction notably > quartz; double refraction low for sections parallel to the prism and high for sections across the prism axis; cleavage parallel to prism intersecting at nearly right angles; biaxial; optically negative; plane of the optic axes perpendicular to prism axis. The occurrence of garnet in association with the sulphides is not mentioned by Ritter. Covellite is described as an alteration product of borrite in a few specimens.

Relations to Neighboring Monzonite Stock.—The mineral characters of the porphyry stock near this mine show beyond reasonable doubt that the dikes at the Evergreen mine are related to it. The rock as exposed one mile southeast of the mine is a monzonite which like the dike rock is characterized by predominant orthoclase in perthitic intergrowth with albite and by abundant grass-green augite. It differs from the dike rock in the absence of quartz, garnet, wollastonite and copper sulphides and in the presence of abundant magnetite. In other phases quartz is fairly abundant. Porphyry occurring on the hill northwest of the Evergreen mine and probably a continuation of the Evergreen dikes is similar in every way to the dike rock of the mine except for the entire absence of sulphides, garnet and wollastonite.

Origin of the Ore.—The origin of the copper sulphides which are the valuable minerals at this mine is somewhat uncertain. They unquestionably crystallized contemporaneously with the other minerals of the dikes and the dikes are without much doubt offshoots from the large neighboring monzonite stock. Several hypotheses of origin may be stated.

1. The sulphide-bearing dike rocks may have been formed solely through magmatic differentiation from the monzonite mass.

2. Sulphides and the materials necessary to form the minerals wollastonite and garnet which are characteristic of the dikes may have been absorbed from the present wall rocks. This view is hardly tenable in view of the sharp contacts between dike and wall rock even where the latter is much brecciated and the absence of variation in the composition of the dike as the walls are approached.

3. The sulphides and materials necessary to form the wollastonite, garnet and quartz especially characteristic of the dikes as distinct from the typical monzonite may have been absorbed by portions of the monzonite magma from wall rocks or veins with which it came in contact. The magma thus modified in composition moved into fissures in the wall rocks and there crystallized as dikes. By the time it had reached its present position it was so cooled and formed such relatively narrow masses that its absorption of the wall rock was slight.

4. The ore-bearing dikes may represent the combined effect of magmatic differentiation and digestion of wall rock.

In the opinion of the writers the abundance of garnet and wollastonite, minerals particularly characteristic of contact metamorphism, in the dikes is strongly suggestive of digestion of calcareous wall rock; wollastonite in particular never having been described in such abundance in rocks of purely magmatic orgin. Such digestion of material probably took place before the rock reached its present position as suggested under hypothesis no. 3 above. The sulphides may have been derived either from the wall rocks through absorption or from the magma by magmatic differentiation. *The deposit under this view represents an endomorphic effect produced by contact metamorphism at the border of a large intrusion of monzonite.*

Later Fracturing and Mineralization.—Subsequent to the intrusion of the ore-bearing dikes the rocks of this vicinity were traversed by numerous fractures and fault-planes. These increase the difficulties of mining by displacing the ore-bearing dikes and forming water-channels. These are not in general mineralized though some are quartz-filled and bordered by narrow leached zones. At one place narrow seams of calcite and quartz cut both dike and schist. One fracture plane traversing the schists in the tunnel showed about one inch of quartz and calcite with a little chalcopyrite. On the dumps a number of fragments were found which showed narrow veins up to one-fourth inch wide composed almost wholly of chalcopyrite, traversing the schist. In one specimen such a veinlet of chalcopyrite cut sharply through typical dike rock bearing chalcopyrite and bornite and enclosing schist fragments. Other fragmens from the dump are fine-grained aggregates of quartz, calcite, chalcopyrite, specularite, pyrite and sphalerite (in part resinous) with a little galena and bornite. Some of the specularite blades penetrate calcite crystals and a few are one-half inch across. The mineralization recorded by some and probably by all of these occurrences is of the vein type and is later than the intrusion of the ore-bearing dikes. Economically it appears to be unimportant.

The ore obtained at this mine is said to average about 3 per cent. copper and $4 to $5 in gold and silver per ton. Its distribution however is sporadic and with the exception of the large chamber-stope on the tunnel level no large bodies have been encountered. Only a few carloads have been shipped and the work is still largely exploratory. The ore is unquestionably to be sought in and near the dikes but since the sulphides are so unevenly distributed in the dike rock no prediction of the probable value or extent of the ore can be made.

PLATE IX. Microphotograph of dike rock, Evergreen Mine. Magnified 20 diameters. The clear white to light gray mineral is quartz; the cloudy light gray mineral in irregular grains is feldspar; the fibrous prismatic mineral is wollastonite; the mottled dark gray and black mineral is principally green augite; the small black areas in the lower southeast portion of the photograph are bornite and chalcopyrite. Note their sharp contact with the other minerals and the generally fresh character of the rock.

LAND CLASSIFICATION, ITS BASIS AND METHODS.[1]

Coal Lands.

W. R. Calvert.

Many of our earlier public land laws, enacted at a period when it was desired to give every possible encouragement to the settlement and development of the west, are anachronisms in the present state of public opinion, which is opposed to the further alienation of the public domain and its natural resources, except under conditions which will effectually safeguard the public interest. Laws and interpretations of laws which were not unduly generous to the pioneer when the West was a wilderness, accessible only with great difficulty and remote from markets of every kind, may with the changed conditions of the last quarter century, grant too great privileges to the few and tend toward that inequality of opportunity which is the bete noir of the modern political philosopher.

With a railroad at the door and a city of 100,000 people but a half day's journey away, 40 acres may easily mean a better living, more comforts, and more wealth, than 4,000 acres of the same land when the only means of transportation west of the Mississippi was a "prairie schooner" or a Missouri River flat boat. Fifty years ago, even a law granting to an individual without charge 5,000 acres of the best coal land in the Raton field in New Mexico could not have induced development in the absence of a market, whereas under present conditions such a grant would confer sudden wealth upon the grantee. Natural resources have not always had the same value they have today. The period is not more than two or three generations back when magnificent walnut and tulip trees even as far east as the upper Ohio Valley were slashed and burned, or split into fence rails because there

[1] Published with the permission of the Director of the U. S. Geological Survey.

was little use and no market for them and could be none until the land that they cumbered had been cleared and occupied by homes.

These pioneer conditions have passed into history. Forests in the United States no longer impede man's advance, but are becoming instead a rapidly diminishing near necessity to his existence. Other resources have been and are playing as important parts in our economic drama as have the forests. For example, coal is the principal source of energy used in our complex transportation systems and is the foundation of a thousand industries. Phosphate is eagerly sought to check the decreasing productiveness of our agricultural lands, and petroleum and its products enter in some form into the daily life of every individual.

Laws rarely anticipate the condition which they are intended to affect. Not only must there be need for their enactment, but there must be widespread recognition of that need before public opinion crystallizes into statute. To a certain extent this is true also of the interpretation of statutes. No enactment is absolutely rigid in its terms. Fundamental laws are written in such general form and permit such discretion in the administrative authority that they may be interpreted to fit widely varying conditions. In fact it is only when so written that they can be properly responsive to the final authority, the people's will. The Constitution of the United States is such a fundamental law. The wise men who were responsible for its comprehensive terms did not dream of an empire beyond the Mississippi, or in the Arctic, or in the tropics far beyond our Pacific shores, yet that remarkably flexible instrument serves equally well now as the basal law for a nation of 100,000,000 people distributed across a continent, along the shores of three oceans, and spanning nearly all the conditions under which human life is possible, as for the original thirteen colonies in a narrow belt along what is at present our eastern seaboard. This adaptation has been brought about by the wise interpretation of the general clauses of our Constitution to cover new conditions as they have arisen.

The rapidly changing situation as to our natural resources, due to industrial expansion and increasing density of population, is

being met in the two ways by which the human race usually meets changing conditions, namely, by the interpretation of old and the enactment of new statutes. Both of these methods follow, neither of them anticipates, public recognition of the altered status. The general movement, defined by the rather indefinite term "Conservation," and involving many complex legal and administrative acts, is advancing in both these ways, namely, by the enactment of new statutes in response to public demand and by the recognition and acceptance of powers and duties, existing in old statutes but heretofore not understood or not acted upon. Upon federal and state officers, both legislative and executive, devolves the duty of translating into action the often indefinite public demand that "something be done" to the end that those natural resources still belonging to the public shall be so managed as to serve best the interests of all. It is with the idea of outlining to the readers of ECONOMIC GEOLOGY a few of the not unimportant practical steps that are now being taken under federal auspices to safeguard and to dispose wisely of some of these resources, that a series of articles on the land classification work of the Geological Survey has been planned.

Subsequent to the enactment of our earlier public land laws up to a comparatively recent period, little restraint was placed on acquiring title from the government to our various natural resources at a nominal price, or even without recompense, due—as has been shown—to the ardent and laudable desire to foster industrial development in the West. Unhampered by the lack of specific legislation or by broad interpretations of laws already in force, agricultural entries or entries under the stone and timber act went to patent when in many instances those entries were made for the real purpose of acquiring control of mineral deposits therein. Since it was obviously impossible for agents of the government, however competent and conscientious, to examine individual entries to ascertain whether the entryman was either innocently or intentionally acquiring title to sources of natural wealth of far greater intrinsic value than the agricultural possibilities, or timber and stone content of the lands involved, the

policy was instituted by the federal government of withdrawing from entry public lands presumably of more value because of their mineral character than for any other purpose. That this policy created inconvenience or even actual hardship to prospective settlers in many instances must be admitted, but that it was not inimical to the general public welfare has been amply demonstrated. Whatever real inconvenience may have been incurred to the bona fide settlers by the withdrawals was removed, with respect to coal lands at least, by the passage of the Act of June 22, 1910, which provided for the separation of surface and underground rights. By the provisions of this Act, actual coal lands may be entered and patent granted for agricultural purposes, reserving the coal to the government. Subsequent to the passage of this Act therefore agricultural development of the West is no longer retarded because of inability to acquire title to lands withdrawn on account of their presumptive coal character or which have been actually classified as coal lands.

The first withdrawal from entry of lands because of coal deposits contained therein was made on July 26, 1906. A large aggregate area in various western states was included in this withdrawal, and this area was increased by subsequent withdrawals till at the close of 1906, the lands thus affected comprised approximately 67,000,000 acres. Later withdrawals were made to cover areas presumptively oil or phosphate bearing or which were presumed to be of value as water-power sites.

Following the withdrawal of public lands the examination and classification thereof follow as a natural sequence. By Act of Congress in 1878, creating the office of director of the Geological Survey, that officer was definitely authorized to classify land, an authority which has never been abrogated.

Field examination of withdrawn lands is made by members of the Geological Survey. One corps of men constituting the fuel section examine areas which are withdrawn from entry because of their presumed coal or oil character; presumptive water-power sites are viewed by engineers of the Water Resources Branch, and the field investigation of other resources is entrusted to those in

the survey best qualified for that purpose by training and experience.

In the field examination of lands the methods employed have become more and more refined. For instance, coal outcrops are now mapped with telescopic alidade and stadia rod, and where natural exposures of the coal are too few to allow of frequent measurements of the bed, numerous prospect pits are opened. As many as 221 individual measurements of coal beds have thus been made in a single township, and in each case the effort is made to keep constant check on variations in thickness or character of the coal from point to point. Data thus obtained give a basis for estimating the tonnage of coal under lands lying back of the outcrop.

Field examination having thus been made the data are compiled and are then reviewed by one of several sub-boards which combined constitute an internal section of the survey designated the Land Classification Board. Each sub-board deals with one phase only of classification. For example, lands are classified with respect to coal by the Coal Classification Board; lands are designated as oil or non-oil by an entirely separate sub-board, and in like manner for the various types of natural resources with regard to which withdrawals are in force. The personnel of each sub-board comprises specialists with respect to the particular questions with which it deals. Each member of the Coal Classification Board, for example, has had at least five seasons' experience in various coal fields and several members also have had practical experience in actual mining.

Prior to the first withdrawals of coal lands, where direct purchase of it was made as such, the price affixed by the government depended only upon the one factor of transportation facilities. Coal lands lying within fifteen miles of a railroad in operation were sold at the uniform price of $20 per acre, and lands located at more than that distance were priced at $10 per acre. This valuation was obviously unfair to the government, since the intrinsic value of the coal was not taken into account. For the government to sell at $10 or $20 an acre of land underlain by a

three-foot bed of lignite may be an advisable policy, but to dispose of several beds of highgrade bituminous coal at the same price does not seem to be in accord with the best administration of our resources. The law relating to sale of public coal lands states specifically that the price shall not be less than $10 or $20 per acre, dependent on distance from railroad, as mentioned above. The logical interpretation of this law therefore is that the values specifically mentioned should be considered strictly as the minimum in any case, but that greater values may be assigned where the amount and character of coal involved warrant. Accordingly, regulations for valuing coal lands were framed and applied to coal land classification. These regulations were modified and amended from time to time as experience in applying them demonstrated the advisability of so doing, and finally resulted in those at present in force. In order to show later the application of these regulations to classification and valuation of coal land, they are here quoted in entirety:

REGULATIONS REGARDING THE CLASSIFICATION AND VALUATION OF COAL LANDS.

CORRECTED TO JUNE 6, 1910.

1. For the purposes of classification and valuation, coal deposits shall be divided into four classes:

A. Anthracite, semi-anthracite, coking, and blacksmithing coals.

B. High-grade bituminous non-coking coals having a fuel value of not less than 12,000 B.t.u. on an unweathered, air-dried sample.

C. Bituminous coals having a fuel value of less than 12,000 B.t.u. on an unweathered, air-dried sample, and high-grade sub-bituminous coals having a fuel value of more than 9,500 B.t.u. on an unweathered, air-dried sample.

D. Low-grade sub-bituminous coals having a fuel value below 9,500 B.t.u. on an unweathered, air-dried sample, and all lignite coals.

2. Lands underlain by coal beds which contain 14 inches or over of clean coal, exclusive of partings, shall be classified as coal land where the coal shows a calorific value of 10,500 B.t.u. or over on an unweather air-dried sample; for coals having a less calorific value the

minimum thickness shall be increased one inch for every decrease of 100 B.t.u. below 10,500. Thus, the minimum thickness of a coal having a B.t.u. value of 8,500 on an unweathered air-dried sample will be 34 inches.

3. Lands containing coals of classes A and B of any thickness at depths greater than 3,000 feet shall be classified as non-coal lands, except where the coal lies within three miles of a point where it can be reached by a 3,000-foot shaft and the depth to the coal from the mouth of the shaft does not exceed 3,000 feet, or where the coal lies within six miles of the outcrop if the bed is horizontal, which distance shall be decreased with increasing dip to a limit of 3,000 feet from the outcrop which shall apply if the bed dips over forty-five degrees, provided that ni no case shall lands containing coals of grades A and B be classed as coal land if the depth from the point of accessibility exceeds 3,000 feet.

4. Lands containing coals of class C of any thickness at a depth greater than 2,000 feet shall be classed as non-coal lands, except where the coal lies within two miles of a point where it can be reached by a 2,000-foot shaft and the depth to the coal from the mouth of the shaft does not exceed 2,000 feet, or where the coal lies within four miles of the outcrop if the bed is horizontal, which distance shall be decreased with increasing dip to a limit of 2,000 feet from the outcrop which shall apply if the bed dips over forty-five degrees, provided that in no case shall lands containing coals of grade C be classed as coal land if the depth from the point of accessibility exceeds 2,000 feet.

5. Lands containing coals of class D of any thickness at a depth greater than 500 feet shall be classed as non-coal, except where the coal lies within one mile of a point where it can be reached by a 500-foot shaft and the depth to the coal from the mouth of the shaft does not exceed 500 feet, or where the coal lies within one mile of the outcrop if the bed is horizontal, which distance shall be decreased with increasing dip to a limit of 500 feet from the outcrop which shall apply if the bed dips over forty-five degrees, provided that in no case shall lands containing coals of grade D be classed as coal land if the depth from the point of accessibility exceeds 500 feet.

Valuation of Coal Lands.

6. The price of coal lands of A, B, and C shall be determined on the basis of estimated tonnage at the rate of ½ to 1 cent per estimated ton for class C; 1 to 2 cents per estimated ton for class B: and 2 to 3 cents per estimated ton for class A, when the lands are within fifteen miles

of a completed railroad, and half that much when at a greater distance, but the price shall in no case exceed $300, except in districts which contain large coal mines where the character and extent of the coal are well known to the purchaser. When, however, topographic conditions affect the accessibility of the coal the land within the fifteen mile limit may be given a lower valuation, but in no case shall it be placed at less than the minimum, and a graded allowance may be made for increasing depth with the same restriction.

7. The rates per ton in the preceding paragraph are based on the assumption that only one bed of coal is present. If more than one bed occurs in any tract of land in such relationship that the mining of one will not necessarily disturb the other, then for the second bed there shall be added to the price of the first bed 60 per cent. of the value of the second bed according to the schedule; 40 per cent. of the value of the third; and 30 per cent. of the value of each additional bed, but the estimated price for coal shall in no case exceed $300, except in districts which contain large coal mines where the character and extent of the coal deposits are well known to the purchaser. Where a bed is over 15 feet thick, the normal value shall be placed only on 15 feet; the next 15 feet or part thereof shall be valued at 60 per cent. of the normal; the next 15 feet or part thereof, at 40 per cent. of the normal; and the rest of the bed at 30 per cent. of the normal.

8. The tonnage shall be estimated for the purpose of valuation on the basis of 1,000 tons recovery per acre-foot.

9. The coal price of lands of class D shall be the minimum provided by law, $20 per acre within fifteen miles of a railroad and $10 per acre when at a greater distance.

10. In all valuations of coal lands any special conditions enhancing the value of the land for coal mining purposes shall be taken into consideration.

11. When only a part of a smallest legal subdivision is underlain by coal the price per acre shall be fixed by dividing the total estimated coal values by the number of acres in the subdivision, but in no case shall this be less than the minimum provided by law.

12. When lands which were at time of classification more than fifteen miles from a railroad are brought within the fifteen mile limit by the beginning of operation of a new road, all values given in the original classification shall be doubled by the Register and Receiver.

13. Review of classification or valuation may be had only upon application thereof to the Secretary, accompanied by a showing clearly and specifically setting forth conditions not existing or known at time of

examination, except in case of entries now pending, or entries made prior to classification.

(Signed) R. A. BALLINGER,
Secretary.

Approved:
April 10, 1909.

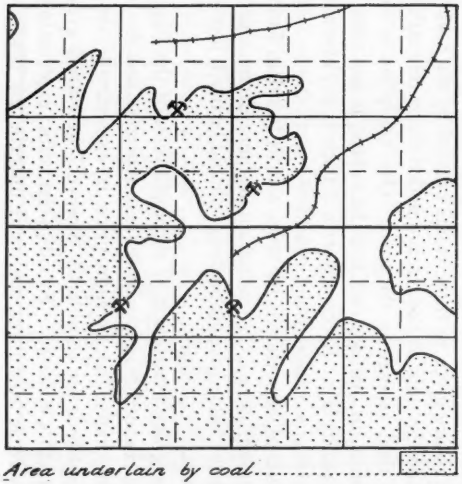
By reference to the regulations quoted above it will be noted that valuation of coal lands is based on various factors in addition to distance from railroad. With respect to all coal except that falling in class D, the price is dependent first of all upon tonnage, which is computed on the basis of 1,000 tons recovery per acre-foot. Since a bed of coal one foot thick and an acre in extent contains approximately 1,750 tons, a recovery of 1,000 tons is a very conservative estimate, as this amount should always be exceeded in actual practice. The price fixed per ton is dependent on the character of the coal, based partly on the heat value as determined by chemical analysis, and partly on its physical quality, since a sub-bituminous coal may possess a higher heat efficiency than a bituminous, yet have a lower market value because of its poor stocking quality. In valuing coal land, therefore, the first question to decide is the placing of the coal in its proper class, whether A, B, C or D.

It will be noted that the Regulations allow a latitude in the selling price between 2 and 3 cents per ton for coal of class A; between 1 and 2 cents for class B, and from ½ to 1 cent for class C. This allows of uniform gradation in price from the poorest coal of class C to the highest grade of coal of class A. This internal gradation within any particular class is influenced by various factors such as the comparative ease or difficulty in mining because of poor roof or floor. excessive water, lack of timber, etc.

From time to time the criticism has been made that the government sale price of its coal lands is excessive and to meet this criticism it may be well to set forth briefly the basis upon which the tonnage values assigned in the Regulations rests. This basis has been discussed fully in Bulletin 424, of the Geological Survey,

entitled "The Valuation of Public Coal Lands," and only a summary need be given here. Royalties actually paid at present by operating companies on private holdings should of course be the governing factor in tonnage price where direct sale is made, and this factor has been of prime influence in fixing values for the several classes of coal. The average life of a mine may be assumed to be twenty years, in which case the first acre will be mined the first year, the last acre the twentieth year, and the average acre in ten years. The purchase value of such land, therefore, should not be more than one half the total estimated royalty value. If that value be again cut in half, because of a possibility that the available tonnage is over estimated, and a still further reduction be made for the sake of conservatism it surely cannot be claimed that the value thus finally reached would favor the government rather than the buyer. Furthermore, this conservative valuation applies only to lands underlain by a single coal bed, and where additional beds are involved it may be claimed with truth that the resultant values tend to ultra-conservatism in favor of the purchaser. In this connection the following quotation from Bulletin 424 is given:

> For lands containing more than one coal bed a reduction in price is made on the additional beds. Thus, the price of the second bed may be only one eighth of its estimated royalty value; that of the third bed only one twelfth; and the prices of all other beds may be estimated at only one sixteenth of the royalty value, to allow for the delay that must usually ensue before the second, third, and other less valuable beds are worked. In general the government price for lands containing several beds will average not far from one tenth of the estimated royalty value.
>
> Moreover, this relation of the government prices to the estimated royalty value is maintained only as to the high-grade, non-coking bituminous coals; for coals of lower grade the minimum price is only one fortieth of the royalty value, as determined by the royalties now charged for low-grade coals in the same general region. Royalties in the West tend to remain uniform, regardless of the variety of the coal (anthracites possibly excepted), but the government prices are scaled down rapidly as the grade of the coal becomes lower, partly to encourage the mining of the lower grade coals, partly because of their lower calorific value and their greater tendency to break down on weathering.



20	20	NON		COAL			
55	85	25	60	55	20		
140	105	135	140	125	20		
140	140	75	60	40	20	20	110
140	140	40	20	20	55	25	140
140	125	20	125	105	60	20	20
140	135	60	140	125	85	125	85
140	140	135	140	135	140	140	140

Large figures give price in dollars per acre

FIG. 65. Figure illustrating government sale price of coal lands where three flat-lying coal beds are present. Left-hand sketch shows relation of coal out-crops to land subdivisions and area underlain by coal; sketch to right shows classification and valuation.

The specific method of applying the regulations to valuation of coal lands can perhaps best be shown by considering typical cases. The accompanying map (Fig. 65) of an area of four square miles in a Colorado coal field, shows mine locations therein, the relation of the coal outcrop to land lines, and the government sale price per acre of the various tracts involved. This is presented as the simplest possible case, since there is only one coal bed present and the strata are practically horizontal. This coal is a high-grade coking variety, and should normally be considered as the most valuable of class A, or according to the regulations, be priced at 3 cents per ton. Dikes are occasionally encountered in the mine workings, however, and a reduction of 20 per cent. is made for that factor, which causes the sale price to be fixed a 2.4 cents per ton. It was found that the coal bed is about 70 inches thick along its outcrop in the area shown on the map. An acre tract underlain by a 70-inch coal bed less than 500 feet from the surface and valued at 2.4 cents per ton, based on 1,000 tons recovery per acre-foot, is worth $140, and this sale price per acre is therefore assigned to those tracts entirely underlain by the coal bed. Prices less than $140 are given to those tracts crossed by the coal outcrop, based on the ratio of the acreage underlain by unweathered coal to the total acreage in the tract. One exception is to be noted, however, in that no tract is to be valued at less than the minimum fixed by law. In other words, if there is any amount of coal whatever in a 40-acre tract, considered workable according to the regulations, that tract is not to be sold at less than $400 or $800 (minimum price), dependent on distance from railroad, even though the value based on tonnage should be much less than those amounts.

In the foregoing illustration of the application of the Regulations to coal land valuation, only one bed is present and the consequent computation of acreage price is exceedingly simple. Where several beds are considered, however, there are a greater number of factors involved. To aid in the verbal explanation of methods where at least three coal beds underlie the land to be valued, the accompanying graphic illustration (Fig. 66) is ap-

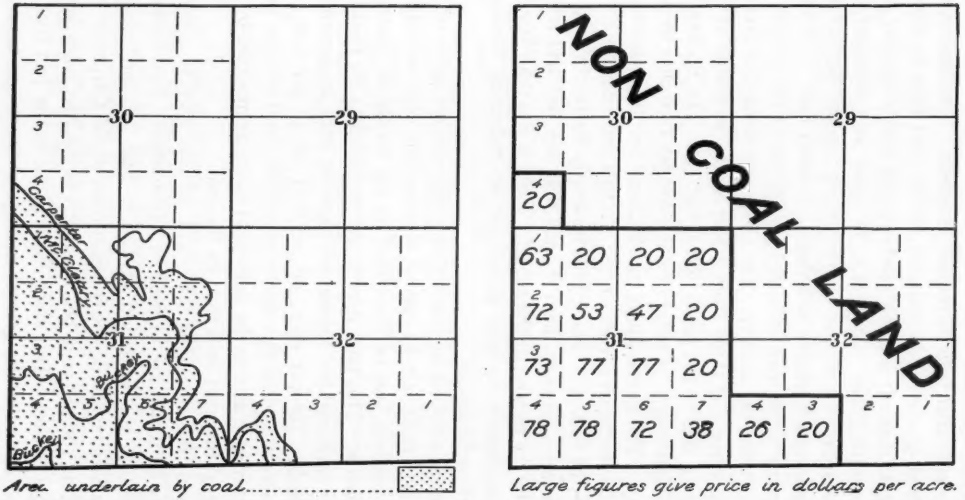


FIG. 66. Figure illustrating government sale price of coal lands where one flat-lying coal bed is present. Left-hand sketch shows relation of coal out-crop to land subdivisions and area underlain by coal; sketch on right shows classification and valuation.

pended. This represents four square miles on the margin of the Bull Mountains coal field in central Montana. The coal in this field is a high-grade sub-bituminous variety and falls in class C of the Regulations. It is a fair stocking coal, which together with its high calorific value, causes it to be rated at 1 cent per ton. Also in accordance with the regulations, a 14-inch bed of this coal is considered workable to a depth of 2,000 feet. The three beds occurring in the area indicated are known as the Carpenter, the McCleary and the Buckey. The Carpenter shows the greatest length of outcrop and thins from 5 feet on the west side of Sec. 30, to about 4 feet on the south line of Sec. 32. The Buckey bed shows the least length of outcrop and averages 15 inches thick in this locality. The intermediate or McCleary bed thins from 5½ feet near the southeast corner of Sec. 31, to 4 feet near the southwest corner of Sec. 30. These beds lie nearly horizontal and the vertical distance between them is such that any bed will not be disturbed by the mining of the others. Each is less than 500 feet from the surface in the area shown and no reduction for depth need therefore be made.

The specific method of determining the acreage price of the various tracts underlain by one or more of the coal beds designated can perhaps best be illustrated by the tabulated statement appended below. This table lists the tracts, indicates the thickness assigned to each coal bed thereunder together with its percentage rating, whether 100 per cent., 60 per cent. or 40 per cent., the value per acre placed on this thickness and the total average price computed for each acre in the individual tracts as modified by the proportion of the tract underlain by the coal.

A study of the foregoing table will disclose several apparent inconsistencies which are in need of explanation. For instance, with respect to the valuation of Lot 7, Sec. 31, the question naturally arises regarding the consideration of the Carpenter coal as the first or 100 per cent. bed inasmuch as the McCleary bed is considerably thicker. This assignment is due to the fact that the former bed underlies the greater acreage in the tract, hence by adopting it as the first bed and the McCleary as the second or 60

Tract Designated.		Coal Bed and Percentage Rating. Per Cent.	Thickness in Inches.	Value per Acre.	Total Average Value per Acre of Tract, as Modified by Acreage Underlain by Coal.
Sec. 30.	Lot 4	Carpenter, 100	60	$50.00	$20.00
		McCleary, 60	48	24.00	
Sec. 31.	NE¼ of NE¼	Carpenter, 100	54	45.00	20.00
	NW¼ of NE¼	Carpenter, 100	54	45.00	20.00
	NE¼ of NW¼	Carpenter, 100	54	45.00	20.00
	Lot 1	Carpenter, 100	57	47.50	63.00
		McCleary, 60	51	25.50	
	Lot 2	Carpenter, 100	54	45.00	72.00
		McCleary, 60	54	27.00	
	SE¼ of NW¼	Carpenter, 100	54	45.00	53.00
		McCleary, 60	54	27.00	
	NE¼ of SW¼	McCleary, 100	60	50.00	77.00
		Carpenter, 60	54	27.00	
		Buckey, 40	15	5.00	
	Lot 3	McCleary, 100	54	45.00	73.00
		Carpenter, 60	54	27.00	
		Buckey, 40	15	5.00	
	Lot 4	McCleary, 100	60	50.00	78.00
		Carpenter, 60	48	24.00	
		Buckey, 40	15	5.00	
	Lot 5	McCleary, 100	60	50.00	78.00
		Carpenter, 60	48	24.00	
		Buckey, 40	15	5.00	
	Lot 6	McCleary, 100	60	50.00	72.00
		Carpenter, 60	48	24.00	
		Buckey, 40	15	5.00	
	Lot 7	Carpenter, 100	48	40.00	38.00
		McCleary, 60	66	33.00	
		Buckey, 40	15	5.00	
	NE¼ of SE¼	Carpenter, 100	54	45.00	20.00
	NW¼ of SE¼	McCleary, 100	60	50.00	77.00
		Carpenter, 60	54	27.00	
	SE¼ of NE¼	Carpenter, 100	54	45.00	20.00
	SW¼ of NE¼	Carpenter, 100	54	45.00	47.00
		McCleary, 60	60	30.00	
Sec. 32.	Lot 4	Carpenter, 100	48	40.00	26.00
		McCleary, 60	60	30.00	
	Lot 3	Carpenter, 100	48	40.00	20.00

per cent. bed, a greater total average price per acre for the tract is obtained. The general rule, therefore, is to arrange the beds according to the percentage rating that will yield the highest possible value for the tract. In other words, where the depth factor is not involved, the comparative tonnage of coal in the various beds in any particular tract controls the percentage rating.

A second apparent inconsistency in the values indicated is in

the relation of the column headed "Value per Acre," and that designated "Total average value per acre for tract, etc." A case in point is with reference to the NW¼ of NE¼, Sec. 31, where approximately two thirds of the tract is apparently underlain by the Carpenter coal bed to which a thickness of 54 inches is assigned. Since this thickness gives a value of $45 per acre, the total average value for the tract should apparently be $30 per acre instead of $20 as shown in the table. This seeming discrepancy is due to the fact that the Carpenter coal bed is burned along its outcrop across the tract in question, thus reducing the acreage of workable coal therein. A similar condition likewise occur in several other tracts valued.

In the application of the regulations to valuation of lands underlain by one or more coal beds which are considerably inclined from the horizontal, several factors are involved which were not considered in the preceding illustrations. Where a coal bed lies horizontal within a tract, its acreage is that of the tract, but where inclined, its area relative to that of the tract is a function of the angle of dip. For example, where a coal bed dips at a 60-degree angle, the vertical projection of the lines bounding a tract underlain by the bed will enclose an acreage of coal measured on the bed equal to twice the acreage of the tract. This increase in area should of course be taken into account in valuation since that valuation is based primarily on tonnage.

A second factor to be considered is that of depth. Coal 1,000 feet beneath the surface is obviously of less value than that near the surface, since not only is there an additional cost in mining because of increased lift, but a greater amount of crushing is involved which necessitates heavier timber, and usually a larger proportion of coal to be left as supporting pillars. In valuation it is assumed that for the first 500 feet of depth little if any excess in mining cost is involved, but from 500 feet to the maximum depth to which the coal can be mined costs increase at a steadily progressive rate. A simple mathematical formula expresses this reduction in value for depth. For illustration, consider a coal of class B workable to a depth of 3,000 feet below the point of

access. Down to 500 feet the outcrop value holds, from which depth the value decreases to zero at 3,000 feet. At 2,000 feet, therefore, the reduction in value expressed mathematically would be $\frac{2000-500}{2500}$, or three fifths reduction from the outcrop value.

These conditions may be illustrated further graphically. Fig. 67 represents an ideal condition which because of its extreme simplicity, seldom, if ever, occurs in reality. An area of one square

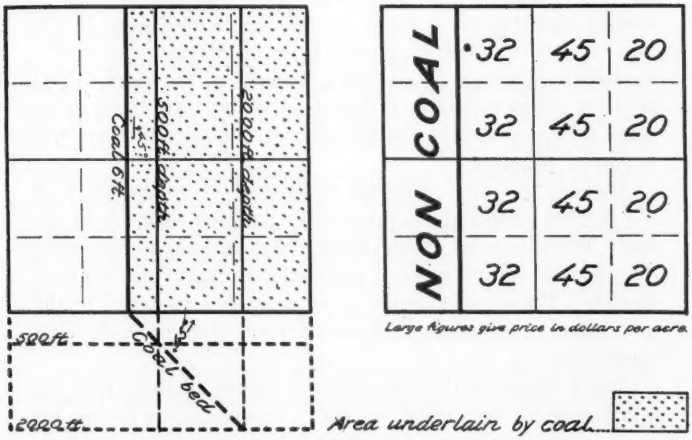


FIG. 67. Figure illustrating classification where one inclined coal bed is present. Left-hand sketch shows relation of coal outcrop, 500-foot, and 2,000-foot depth limit to land subdivisions; sketch to right shows classification and valuation.

mile is shown in this illustration, across which a coal bed 6 feet thick is assumed to outcrop in a straight line parallel to the north-south subdivision boundaries and in such relation to them that the 500-foot depth contour falls on one such boundary. It is assumed further that the coal dips uniformly 45 degrees to the east, which places the 2,000-foot depth contour in the east tier of tracts as indicated. For the purpose of valuation, consider that the coal is rated at 1 cent per ton and will fall in class C, which assigns a

2,000-foot depth limit of workability. In the SW¼ of SE¼ of the section this bed lies at an *average* depth of 1,200 feet. A 6-foot bed of coal within 500 feet of the surface, if horizontal, is worth $60 per acre based on 1 cent per ton and 1,000 tons recovery. Applying the formula quoted in the preceding paragraph, the value per acre of the tract in question is $60—$\left(60 \times \frac{1,200-500}{1,500}\right)$, or $32. This value, however, does not take into account the increased acreage due to the dip. Beneath a 40-acre tract the area of a coal bed which dips 45 degrees is 1.41 times the area of the tract, as may easily be demonstrated mathematically. The value of the tract in question, therefore, is $45 per acre. Since conditions are identical for the three tracts to the north of that discussed, the government sale price per acre will be similar for each.

Applying the same principles outlined above to the SE¼ of SW¼ gives a value of $84 per acre for that part underlain by the coal. This is reduced to an average of $32 per acre for the entire tract because of the ratio of coal-bearing area to the non-coal portion. The same price per acre naturally is assigned to the three tracts to the north. The tier of tracts adjacent on the west is non-coal.

Only a glance at the illustration is needed to show that the actual value per acre of the east tier of subdivisions in the section is a very small amount. According to law, however, these tracts cannot be sold as coal land at less than the minimum price of $20 per acre, assuming that the land is within fifteen miles of a railroad.

In inclined strata where more than one coal bed is involved, the consequent valuation of lands is based on the principles outlined above combined with those discussed in connection with Fig. 66. The proper percentage rating of the various beds where so inclined is in many instances determined only upon computation to decide which rating results in the highest acreage value.

Many other factors are involved in coal land valuation concerning which the brevity of this article forbids detailed discussion or

illustration. Structural conditions, for instance, notably affect the cost of mining and should therefore be considered in valuation. Where faults are present there is necessarily a large amount of dead work in mining. The character of the floor and roof, especially the latter, influences mining cost materially. As a rule, partings in the coal are undesirable factors, yet in many cases a parting is of actual benefit. The character of the parting is also to be considered in valuation. For example, a 3-inch bone parting which "freezes" to the coal may be more costly to handle than one of shale or sandstone considerably thicker but which is easily separated from the coal in mining.

One of the most troublesome features with respect to coal valuation results from the habit of coal in certain formations and in certain localities to present sudden changes in thickness. It is under such conditions that abundant data are essential in order that even a close approximation of tonnage can be made. Where such data are available, however, it is possible in many instances to outline, with the feeling that the result is not greatly in error, the shape and extent of the basin in which the coal was formed. This one feature, however, is a subject too comprehensive to be discussed in this paper.

A concept of the activity of the Land Classification Board with respect to coal land classification may be obtained from the reports made to the director of the Geological Survey at the beginning of

SUMMARY OF COAL CLASSIFICATIONS. CLASSIFICATIONS UNDER THE SECRETARY'S REGULATIONS OF APRIL 10, 1909.

Date, 1911	Coal with Valuation. Acres.	Cool without Valuation. Acres.	Non-coal. Acres.	Restored without Classification. Acres.	Total Acres.	Value as Fixed.	Value at Minimum Price.
Prior to January	10,027,445	854,602	22,476,932	2,126,668	35,485,647	607,413,931	168,876,373
January	451,726	18,938	447,383	693	918,740	10,835,848	5,621,532
February...	216,418	577	977,409		1,194,404	6,587,486	2,669,200
March	1,207,219	13,529	1,583,625		2,804,373	37,971,740	21,293,141
Totals ...	11,902,808	887,646	25,485,349	2,127,361	40,403,164	662,809,005	198,460,246
Net[1]	11,163,277	775,105	24,755,687	2,044,560	38,738,629	615,557,397	186,912,303

[1] Outstanding classifications, deducting duplications.

each month for the several months preceding. Appended is such a summary in tabulated form for March, 1911, followed by an additional statement regarding classification, withdrawals, and restorations:

LAND CLASSIFICATION BOARD.

REPORT FOR MARCH, 1911.

During the month 1,220,748 acres were classified as coal, at a value of $37,971,740, while 1,583,625 acres were classified as noncoal, making a total coal appraisement to date of 15,248,714 acres with a value of $668,433,342, and a total of noncoal classification of 36,612,987 acres. The lands classified as coal have a value of only $236,460,613 at the minimum price allowed by law. Two coal land withdrawals aggregating 96,461 acres were made in Nevada and Utah, and six restorations aggregating 1,951,021 acres were made in Colorado, Montana, New Mexico, South Dakota, Utah and Wyoming, leaving a total of 78,152,808 acres withdrawn at the end of the month, pending classification as to coal character.

It is realized that the methods of coal land classification are accorded too brief treatment in this article to be of the greatest possible value to those interested in the subject. However, the main principles are set forth, and, it is hoped with sufficient detail to show clearly that such classification is fundamentally scientific in character, based on careful field examinations and exhaustive consideration of all data bearing on the question of coal land valuation.

THE PROGRESS AND PROSPECTS OF MINING IN WESTERN AUSTRALIA.[1]

By A. Montgomery, M.A., F.G.S.
(State Mining Engineer, Western Australia.)

Western Australia is a vast country, justly described as one of "magnificent distances." It comprises 975,920 (or nearly a million) square miles, and extends over twenty-one degrees of latitude, the north part being within the tropics (in 14° south latitude) and the south approaching the cooler portion of the temperate zone (in 35° south latitude). The climate, therefore, is very different in different parts of the state. There is a good rainfall along most of the west coast, averaging thirty to forty inches annually, but as we go inland it decreases, and on about 57 per cent. of the area of the state the annual rainfall is under ten inches. Sub-arid conditions therefore prevail in a large portion of the interior, and provision of permanent supplies of fresh water becomes a first necessity of settlement. In the summer months the shade temperature often rises to over 100° F., and in the tropical parts of the country there is naturally a high average annual temperature, but south of the tropics for the greater part of the year the climate, though warm, is not by any means excessively hot, and in winter it is often quite cold, with occasionally frosts at night. The dryness of the atmosphere enables people to endure a much higher temperature without discomfort than is possible in more humid regions. On the whole, the climate of sub-tropical Western Australia must be regarded as an exceedingly pleasant one, and even within the tropics it has been found that Europeans can live and work with much comfort and excellent health.

There are no high ranges in Western Australia, the altitude of

[1] Abstract of Paper read before the Colonial Section of the Royal Society of Arts, on November 29, 1910.

its highest portion being only about 4,000 feet. The greater part of the interior of the country consists of plains 1,000 to 1,500 feet above sea-level, broken by low ridges and island-like low hills. Over the main portion of the central and eastern gold-fields there are very few outstanding ranges of hills of any magnitude, but from Peak Hill northwards the country becomes much more hilly, and distinct mountains of some altitude are often visible. In the south of the state also there are some fairly high and steep mountain ridges. There is, however, no great range sufficient to form a source of permanent rivers, and, except in the northwest and southwest regions, where there is a good rainfall, running streams are unknown except during rains. The plains are generally very flat basins dipping towards depressions occupied by salt lakes and saline clay pans. On the edges of these plains there are very often precipitous escarpments ten to fifty or more feet high, known locally as "breakaways," which mark the margins of old lake basins of which the plains were the bottoms. At the top of the escarpments we frequently come on small plateaux, often very level, which are relics of an older marine plain, and on these there are frequently sand dunes, fringing the old lake basins. In the lake-basins the bed-rock is often at a very shallow depth beneath the surface, or even outcropping, but frequently it is covered with detrital material to considerable depths, many wells being sunk seventy to eighty and even over one hundred feet before reaching the bed-rock. It is plain, therefore, that in those old lake basins there has been a great deal of levelling up of old hollows in the bed-rock with detrital materials.

In the districts of the southwest portion of the state, where there is a fairly good rainfall, there are extensive forests of heavy timber, and more inland there are still good timbered belts, which provide excellent firewood and mining timber for the mines. In the Murchison and Mount Margaret districts, however, the heavier eucalyptus timber is replaced by small trees ("mulga"), which supply good firewood and make useful but not first-class mining timber. Still further north the country becomes very open, and is covered with various varieties of grass

and spinifex, forming good pastoral country. In these parts of the country it is often very difficult and expensive to procure mining timber and firewood, the trees being confined to narrow belts along the main watercourses. The country is, as a rule, remarkably easy to traverse, there being little or no difficulty, other than that of obtaining water, in taking vehicles over it in any direction without having to make roads. The "bush" is very open, and can often be traversed quite readily in a buggy, or even, in a good many places, in a motor-car. This ease of getting about explains at once the extraordinary way in which the goldfields were overrun by prospectors within the first ten years of the gold discoveries. It also explains why it is possible to lay down railways for not much over £1,500 to £1,800 per mile.

Gold and other minerals are found more or less all over the explored portions of Western Australia, the principal metallic minerals being gold, tin ores, copper ores, lead ores and iron ores, while coal is the most important non-metallic mineral. The metallic minerals occur in very old igneous and sedimentary rocks, the geological age of which is not yet determined, beyond that it is pretty certain that the most of them are older than the Cambrian period. There is a very complex system of exceedingly ancient metamorphic rocks mingled with igneous intrusives, many of which have become converted into schists, and which may be roughly grouped together as the auriferous greenstones. Breaking through these there are great granitic intrusions, which, in turn, have been pierced by later dykes, both acidic and basic, of different ages. In this great series of old rocks there are doubtless both sedimentary and igneous products of many different ages, the relations of which to one another have not yet been worked out. Lying unconformably on these oldest rocks, we find here and there throughout the country small patches of a younger but still extremely old formation of sedimentary slates and schists (known as the Mosquito Creek series), and apparently of later date than these are the fossiliferous Cambrian beds of the northern part of the state. In the north also

we have a large development of Devonian rocks, and in the north and west considerable areas of Permo-carboniferous strata. In the most southerly of these last the Collie Collieries have been opened up. The occurrence of patches of cretaceous marine strata and tertiary to recent limestones in widely-separated parts of the state shows that much subsidence and elevation of the country must have gone on since the coal measures were laid down, and numerous physiographical and geological considerations have led me to the conclusion that the country owes the present shape of its surface very greatly to the fact of its having been wholly or in great part submerged beneath the sea within post-Tertiary times.

This very incomplete sketch of the geological history of the country may serve to assist in comprehending some of the features met with in mining in it, especially for gold. Except for coal, phosphate rock, gypsum, salt, bauxite and some few other minerals, and when considering the distribution of alluvial gold and tin ore, we may put to one side, from a mining point of view, all the country occupied by the strata of later date than the Devonian period. In the Devonian system we have a very interesting series of auriferous conglomerates (the Nullagine conglomerates), which are in many respects closely analogous to the "bankets" of South Africa, and it is interesting to note that in these beds the gold is pretty certainly of alluvial origin, derived from the erosion of the underlying Mosquito Creek and auriferous greenstone series, both of which teem with auriferous veins. The Devonian and later strata are comparatively little crumpled by orogenic movements, and show little, if any, evidence of ever being penetrated by mineral veins, and it seems very clear that the period of formation of the mineral veins in the older rocks was long anterior to the Devonian, and probably also to the Cambrian period. All the pre-Cambrian strata, whether igneous or sedimentary, are greatly plicated and contorted, the axes of folding running north-northwesterly in the southern part of the state and northeasterly in the northern, conformably with the general direction of the western coast-line. The complex of

ancient intrusive and metamorphic rocks in which the mineral veins occur, and which we now find at surface, was doubtless once deep in the base of a rising region, probably forming a mountain chain like the Swiss Alps or the Cordilleras of South America. There is much reason to regard it as most probable that the quartz veins carrying the gold and minerals were of very deep-seated origin, most of the vein stuff being really more or less sheared country rock transmuted into quartz by metasomatic change. Most probably they are the result of pneumatolytic processes operating—very likely more or less in connection with volcanic activity—during the period of mountain-forming movement, which was certainly mainly pre-Devonian and probably pre-Cambrian.

The principal gold discoveries may be arranged in belts which correspond very well in direction with that of the general axes of folding of the oldest strata. It is noteworthy that the main granitic areas have so far been found to contain few mineral veins, and that the latter are usually in the greenstone schists and dioritic intrusives not far from the contacts with the granite. When payable mineral veins have been found in the granite they have in almost all cases been quite close to the greenstone contacts. Many of these contacts have probably been lines of very severe faulting movement, the greenstones along the contact being very much sheared and foliated, and the granite being also in some cases converted into schist, which a short distance away soon merges into gneiss and granite. Some of these shear zones along the granite contacts are of great length and persistency, one passing through Southern Cross, for example, being traceable for over sixty miles at least, and they are very notable as containing several important mines, and very numerous smaller auriferous veins.

It has rarely been recognized that it appears to be a very common feature of many West Australian ore bodies that they have been disrupted, by earth movements or faulting, along the planes of the lodes themselves, these movements subsequent to the formation of the ore bodies having re-opened the old line of fracture

in which the lode was first formed. The good stone is often found suddenly to "cut out"—a term always highly suggestive of some form of faulting—and, as a rule, little search is then made to recover it. Frequently there is a reef of poor or barren quartz present alongside the valuable one, which is of later date of formation than the latter, and which is left standing while the good ore is taken out, but it is uncommon to find any rational deduction being made from the fact that such a condition is *prima facie* evidence that there was a reopening of the old reef fissure to enable the later poor reef to be formed, and that in the course of the faulting movement which would result, the older reef would almost certainly become much broken and displaced. When it disappears suddenly and the poor reef continues, it is quite usual to assume that the two have joined one another and that the values are simply vanished, instead of search being made for the dislocated continuation of the good ore. It is not contended that this explanation applies to all or even to the most important cases of loss of values in the lodes, but many instances of it have come under my own observation, and there is a good deal of reason to think that many cases of curious separation of lenses of ore containing values may really be explainable by the faulting of an originally continuous body. In dealing with these lodes we are probably handling the case of deposits formed in very early geological times, during a period of much earth movement and plication of the region containing the mines, and therefore particularly liable to show much dislocation of the contained ore veins.

Another characteristic feature of the lodes of Western Australia is the unusual amount of secondary enrichment which appears to have gone on in most of them near the surface, especially in the zone of oxidation above the water level. This has often led to much disappointment when the deeper parts of the lodes have been reached, but it is a feature which is now becoming much better understood than formerly, and for which allowance is to be made. There is, however, much doubt yet as to the depth below surface to which its effects are perceptible.

In some cases the values disappear so suddenly at the water level that there is a temptation to speculate on the possibility of their having been removed by leaching upwards, there being a certain amount of constant drawing upwards of the ground-water by capillarity to replace the moisture removed by surface vegetation and evaporation. In an arid climate this action may be expected to be more marked than in a humid one. The possibility seems sufficiently feasible to require some sinking to be done in such cases in order to pass through what may be not an enriched but an impoverished zone.

As a matter of fact, good values have been found in Western Australian mines at the greatest depths to which mining has been carried, namely, the 2,650 feet level of the Great Boulder Mine. So far as work has gone at that level, it is true that values have not been so satisfactory as at the 2,500 feet level, and there has been much fear expressed in consequence that this famous mine was at last failing. But some good ore has been obtained, and it must be remembered that at all the levels it has been often easy to miss the best ground until a great deal of exploration has been done. The following of ore in the Western Australian mines is anything but a simple proposition, the ore often being hidden behind what are apparently the well-defined "walls" of the reef, while the lode stuff between these is of little or no value. In almost all the mines of Kalgoorlie it has been found essential to do a great deal of boring across the strike of the reef to locate hidden ore, and the first drive along the lode has often been anything but a true test of its value. This local peculiarity must be recognized and allowed for, and time given to open the ground pretty thoroughly before jumping to conclusions about extinction of values. The whole history of the Boulder Mines from below the oxidized zone has shown a succession of pessimistic forecasts of its early decease, and from time to time the prospects of first one and then another of them have appeared very doubtful. Time and again, however, further exploration has brought about new developments and the position has improved, and there is therefore always much hope that perseverance will be well rewarded.

All the principal mines show much more variation in their values at different points than is generally understood by the public, and it is owing to this feature of them that it is so difficult—indeed. almost impossible, in many cases—to make really reliable estimates of ore reserves. The only safe course is to keep the mining development a long way ahead of the ore-breaking, to give time for fresh ore bodies to be picked up before the older ones are worked out.

It is undeniable that in Western Australia, as in all other parts of the world, the lower levels of the mines have not been so productive as those nearer the surface, but it does not seem to me that in this respect they have shown any more lack of permanency in depth than those of most other mining fields, nor is there any satisfactory reason yet apparent why values should not be found to persist in them to quite as great depths as in any other mining region say to 4,500 feet as in Bendigo, or even to the immense depth of 6,000 feet at which mining in South Africa has been seriously contemplated. The grounds on which early extinction of values has often been predicted are mainly quite theoretical, and, notwithstanding that great advances have been made towards formulating a science of ore deposits, it cannot be denied that there is still very great conflict of opinion among the best authorities on the subject on the most fundamental propositions as to the mode and conditions of ore formation. For example, not very long ago a discussion was published as to the origin of a certain pyritic ore body, in which one leading authority held the view that it had been formed by magmatic differentiation from an igneous mass, another that it was an ordinary lode of hydrothermal or pneumatolytic origin, and a third that it was a metamorphic sedimentary deposit, all radically different and incompatible conceptions. While one school of opinion regards ore deposits as more or less chemical concentrations from the more superficial rocks of the earth's crust, due to circulation of liquid solutions through them, and another holds equally strongly that they arise mainly from emanations from plutonic sources, there cannot be said to be any accepted theory

of ore formation on which it is safe to build practical conclusions as to behavior of lodes in depth. The various hypotheses may be useful to guide exploration, but the only practical course is to sink down to see what the ground will show. This has been the mining maxim from its earliest days, and it is still as necessary as ever. No theory is yet so firmly established as to justify deductions being made from it without the check of actual trial.

A great deal of the fear that is expressed as to permanency of ore deposits in depth is often founded on what is really an entirely unproved assumption, though it has a certain amount of *prima facie* probability, namely, that in a deposit formed by ascending hot waters the metals would be likely to be in solution in the deeper zones while at higher temperature and under high pressure, and would only be deposited as in ascending through the crust of the earth the temperature and pressure are reduced and the solutions come in contact with more superficial waters carrying precipitants. It is somewhat inconsistent that this view should be put forward as a reason for expecting falling off in value in reefs like those of northern New Zealand, which seem plainly to be of hydrothermal origin and outcropping probably at no great depth below the original outlets of the hot springs which formed them, and also for the pneumato-genetic lodes of Kalgoorlie, the portions of which now accessible to us have most probably been formed at great depths under pneumatolytic rather than hydrothermal conditions. And when we come to consider the case of the gold-bearing alaskites, where we seem to be dealing with a transition stage between plutonic dykes and ordinary reefs, it is difficult to understand that either temperature or pressure can necessarily be the determining factors of deposition which they have often been assumed to be.

It seems to me that the mining industry has a right to protest against the very unscientific attitude taken by some persons claiming to be authorities who have allowed themselves to be carried away by deductions from the theories which they adopt with regard to ore deposition, and issued dogmatic statements as to what *must* happen to ore deposits in depth. In the present state

of the science any such views can only be tentative, and should be clearly understood to be so. They carry more weight with the investigating public than ought to be allowed to them, views which are the mere speculations of an authority being often taken to represent the demonstrated conclusions of science, and in consequence exploratory work which would be undertaken if these ideas had not been put forward may be restricted or abandoned, to the great detriment of mining.

DISCUSSION

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

MAGMATIC DIFFERENTIATION A FACTOR IN THE OCCURRENCE OF ORE-SHOOTS.

While engaged in the examination of various mines, in the Pachuca (including Real del Monte) district, Hidalgo, Mexico, it appeared to the writer that the occurrence of the ore-shoots was closely associated with certain phases of the country rock and that these phases were the result of magmatic differentiation.

It is the purpose of this paper to give in a general way the data upon which this opinion is based. As the mines were examined while under professional engagement I do not, at the present time, feel at liberty to go into any detail concerning them.

Briefly the geological sequence of the district may be outlined as follows:

1. The most recent sedimentary rocks in the district belong to the Cretaceous period.

2. The Cretaceous rocks were penetrated by large intrusions closely related to andesites. These intrusions occur as large elliptical dome-shaped masses striking northwest-southeast. Their exposures are from ten to eighteen miles long, from eight to twelve miles wide and they probably have a much larger extent.

The ore-bodies of the Pachuca and of the Real del Monte districts occur within one of these dome-shaped masses. A consideration of the macroscopic and microscopic characteristics of

this intrusion and the association of the known ore-bodies of the district with certain phases of the intrusion will constitute the essential features of this communication.

3. A period of erosion during which the contour of the andesite porphyry was changed.

4. The introduction of a later andesite (very acidic) which occurs as flows and rests uncomfortably on the earlier andesite. Inasmuch as these later andesites are in no way associated with the ore-bodies of the district they will not be further considered.

5. A second period of erosion during which large areas of the later andesite were eroded again exposing areas of the andesite porphyry domes.

6. The introduction of a series of rhyolite flows which partially covered both the later andesite flows and the primary andesite masses. These rhyolites are in no way related to the ore-bodies of the districts and will not be considered further.

7. A third period of erosion which exposed large areas of the andesite flows and of the primary andesite domes. During this period there were many intrusions of quartz-porphyry dikes which cut both the andesites.

8. A period of areal faulting when the veins of the district were formed. This faulting was probably due to subsidence and adjustment caused by the large primary andesite-porphyry intrusion cooling at depth. During this period fissures were formed, rock between the walls was brecciated and there was a heavy silicification but practically no economic values were brought into the veins. It was essentially a period of fissuring, brecciation and silicification.

9. A second period of faulting with movements, relatively, much less than during the former period. It was during and immediately subsequent to this secondary faulting that the veins received their commercial values. During the period the economic values were being deposited; there was some silicification but, relatively to the primary silicification following the primary faulting, it was slight.

10. Erosion and a few minor faults.

As studied in the field the andesitic dome-shaped mass, in which the ore-bodies occur, is not homogeneous. For the most part the color is a light grayish-green, the rock is porphyritic and breaks irregularly. Here and there within it there are variations. These variations in the extreme cases have a dark reddish-brown to a dark-greenish color, break with a conchoidal fracture, are porphyritic and very tough. Whereas the predominant, or lighter hued types average approximately 65.0 per cent. of silica, the dark-colored variations are more basic, averaging only a few tenths more than 60.0 per cent. of silica. Where observed over the surface and in the various workings, between the two types, there is no definite dividing line—the one imperceptibly graduates into the other. Within the predominating or acidic phase the basic occurs in the most irregular manner. In many cases its occurrences are roughly lenticular; strike in any direction and dip at any angle. In extent these somewhat lenticular masses vary from a foot in diameter up to masses several thousands of feet long, several hundreds of feet wide and two have been proven to a continuous depth of eighteen hundred feet. In some places the two phases irregularly alternate, both horizontally and vertically, with each other. In these particular instances either type may predominate.

Operations in the Pachuca district have demonstrated that the tough basic phases are not favorable for the formation of ore and that all the large ore-bodies are found in the acidic types. Thus from an economic standpoint it was necessary to determine whether these variations belong to a single mass with many differentiation facies, or, whether on the other hand, they are each separate units of structure occurring as dikes, sheets or flows. In the field, the most careful scrutiny failed to find more than one recognizable division and all observations indicated that the two phases are simply differentiations of a common magma. For petrographic study a series of specimens illustrating the range of field appearances were submitted to Dr. Charles P. Berkey, of Columbia University, who has communicated with me regarding them as follows:

The acid type is plainly a porphyritic rock with a groundmass of

somewhat trachytic habit composed chiefly of medium plagioclase. The groundmass is never coarse and the fluxion structure, which is rarely present, is never strongly developed. The phenocrysts are also chiefly medium plagioclase, with an occasional chloritic area representing original ferro-magnesian minerals while rarely a very badly corroded quartz is to be seen. These last are always mere skeletal remnants indicating severe attack upon them in the final magmatic changes. The usual accessory constituents are present.

Secondary products are abundant chief among which are carbonates (probably calcite), chlorite, epidote and secondary quartz. There is no complicated history indicated except the small traces of fissuring represented by minute crevices and a chemical attack represented by the greenish and uniformly distributed secondary products. There is a little pyrite mineralization in rather large grains.

The basic type is also plainly porphyritic in habit and both groundmass and phenocrysts are chiefly plagioclase of medium composition. In this type, however, the ferro-magnesian constituents are noticeably more abundant. Derivatives from hornblende, augite and possibly biotite and olivine are present. Much more rarely than in the acid type a skeletal remnant of quartz may be found. Some specimens show fluxion structure but in most cases this is obscure.

Secondary products are abundant, the most common being carbonates and chlorite. There is very little epidote and quartz. Very minute crevices rehealed with calcite occur as in the other type.

This rock has had the same history as the more acid variety.

The two types differ most on the following points. The acid rock has more original hornblende, less pyroxene and less secondary chlorite. These differences are consistent with the known chemical difference of 5.0 per cent. of silica. There are no strikingly unlike varieties. The great similarity of composition, texture and alteration in each type leads readily to the belief that they are all representatives of a single parent magma and that they probably represent a single parent mass. Even the extreme acidic and basic types have no differences of large consequence and are consistent enough with the differentiation of a single mass.

The most inconsistent features for so large an intrusive mass are texture, the persistent porphyritic habit and the occasional fluxion structure. In spite of these, however, there is no reliable ground for regarding the whole series as anything other than a magmatic differentiation. While the extremes of the series are noticeably unlike, any two adjacent ones are almost identical in all essential respects.

Regarding the rocks therefore as intrusive, the term andesite is not strictly appropriate for their classification. Nor is diorite very suitable

for a porphyritic rock of this character. In order to indicate as fully as possible the field relation and the slight mineralogic differences, the acid type may be called a quartz andesite porphyry or a dacitic porphyrite and the basic type may be called a medium andesite porphyry or a hornblende pyroxene porphyrite.

CHARACTER OF THE VEINS.

The veins are not simply fissures filled with silica and economic minerals but in a general way may be described as crushed zones varying from a few feet up to forty or fifty feet in width. In some instances both footwall and hanging-wall are clearly defined. In many places there is no observable dividing line between the ore-body and the wall-rock and the limits of economic ore can be determined only by sampling.

During the period of vein formation there were at least two distinct movements.

1. A primary movement which crushed and brecciated the rock along the zone of faulting. This primary movement was followed by the introduction of solutions which were highly silicious. The silica formed vein material in two ways: (*a*) It attacked the crushed and brecciated rock replacing it metasomatically. (*b*) It deposited in the openings around the breccia and more or less cemented them together. Little, if any, economic values were associated with this primary movement. It was essentially a movement of crushing and silicification.

2. A secondary movement for the most part within the zone of the primary crushing. There was, relatively, far less displacement during this secondary movement than during the first. The rock broken by the primary movement and more or less cemented by silicification was again broken—silicious solutions again permeated the breaks but, relatively to the primary, this secondary silicification was very slight. It was during this secondary silicification that argentite, the principal economic mineral, was brought into the veins and deposited.

Since the deposition of economic values was subsequent to the secondary fracturing, it is patent that the occurrence of ore is closely associated with the character and the intensity of the

secondary fracturing. Where the primary fault broke through a basic phase of the rock, the crushing was not as intense as within the acidic—the brecciation units were larger. Further, the basic phase was not so susceptible to metasomatic silicification as the acidic. The replacement did not penetrate the breccia units so deeply nor was the metasomatism nearly so complete—the altered portion being a tough, so called, bony-quartz rather than a typical friable quartz which latter type characterizes the metasomatic product of the acidic phase of the rock. This tough bony-quartz when cemented by further additions of silica rendered this portion of the vein firmer and tougher than the country rock so that when the secondary movement occurred, instead of a distributive crushing movement over the entire breadth of the vein which would reopen the original zone of fracturing for its whole width, there was more or less of a gliding movement over a very narrow width. In many places where the original fracturing passed through a basic phase of the rock the secondary movement did not maintain within the vein *per se*, since, the movement left the vein and closely followed either the hanging or the foot-wall, the residual effects being now manifested in a narrow gouge streak with practically no values. In other instances the secondary movement did pass through this tough tightly cemented portion of the vein but always as a very narrow irregular fracture. For the most part these narrow fractures are well mineralized with argentite but the width is by far too small to even approximate pay ore. Thus, where the vein passes through a basic phase of the rock, it is as wide and the quartz is as pronounced as where it passes through the acidic phase but economic values are not found.

The acidic phase of the rock on the other hand was more amenable to crushing than the basic and with the primary movement freely brecciated leaving many and in some instances large cavities. It was more susceptible to silicification than the basic. Large brecciation units were completely replaced and the metasomatism was for the most part very pronounced, the final product being a friable quartz. In many places there was insufficient silica to completely fill the spaces between the brecciation units.

Thus where the vein passed through the acidic phase of the rock, the primary crushing and silicification did not leave it as tight and tough as where it passed through a basic phase, consequently, when the second movement occurred this portion of the vein was not in a condition to resist fracturing but moved and crushed throughout its entire width and opened up so as to afford passages for the introduction and deposition of economic values.

Thus it would appear that for this particular district the occurrence of the ore-shoots is closely associated with a certain differentiation phase of the original magma. In this particular instance the favorable phase is the more acidic facies. The difference in the amenability of the two phases of the rock, where all general conditions are the same, for the formation of economic ore (ore-shoots) is due to the fact that the one phase is more easily fractured than the other and also that the same phase is more susceptible to silicification. The occurrence of the ore-bodies is essentially the resultant of two variable factors—the one physical —the other chemical and thus it is probable that in other districts ore-shoots may be found associated with a basic phase of the country rock while the acid facies is found to be unfavorable.

In the district under consideration there were two periods of movement and silicification and the primary silicification was one of the most important features which determined the limits of pay ore. In a great many districts, however, there has been for all practical considerations only one period during which there was movement and mineralization. In many such cases, although the line of fracturing maintains for considerable distances, yet, economic ore-bodies or shoots are restricted to one or more, relatively, quite short distances. In many such occurrences the writer has observed that along the strike of the fracturing the country rock varies—that within certain phases the movement was restricted to a narrow impervious gouge streak—that within other phases the movement was distributive over a more or less considerable width—that within this width the rock was brecciated leaving spaces for the introduction and deposition of mineralizing solutions and that the occurrence

of the ore-shoots is closely associated with a certain differentiation phase of the country rock.

That the final products of magmatic cooling are rarely homogeneous but present, even within quite restricted areas, marked differentiation is recognized by all field-workers. Thus with granites we may have a feldspar—a hornblende—a quartz—or even a mica facie forming a differentiation within the more normal and predominating type. Similarly in other igneous rocks we frequently find one of the essential minerals so abnormally abundant as to form a facie which differs more or less from the predominating phase. In most instances where there has been segregation during cooling the differentiation facies, because of pronounced differences in the color or size of the essential minerals, are readily distinguished in the field. On the other hand, there are instances of differentiation which are not so readily identified since the essential minerals are of approximately the same appearance and the differentiation phases can be appreciated only by a petrographic examination of a representative series of specimens.

That an appreciation of magmatic differentiation as a factor in the occurrence of ore-shoots can be of economic importance was recently demonstrated by the writer in Arizona. At the locality under consideration the predominating rock in the field presents a greenish to light-green groundmass containing numerous whitish feldspar phenocrysts. Inclosed in this greenish portion, the one imperciptibly graduating into the other, are irregular dark bodies with a dark groundmass containing somewhat glassy feldspar phenocrysts. The light-green variety was found to contain 44.5 per cent. of silica and the dark 54.5 per cent. A petrographic study of representative specimens of the two varieties was made by Dr. Berkey. A summary of his conclusions is as follows: The specimens are both to be regarded as andesites. There is not a sufficient difference in their mineralogical composition or habit to separate them as distinct types and there is nothing to indicate that they are not differentiation phases of the same magma.

Inasmuch as the dark-hued acidic variety is the less abundant it may be regarded as a differentiation phase from the more predominant, more basic, light-green variety.

At the property, where the above observations were made, the developed ore occurred in a well-defined shoot and this shoot was found to maintain within the vein where the faulting crosses a dark acidic differentiation phase of the andesite. So pronounced is the differentiation that locally it is referred to as a dike and the vein is said to make ore where it crosses the dike. Along the vein, south from the ore-shoot, the rock within a distance of twenty feet changes from a pronounced phase of the acidic type to the basic and within this distance values lessen from good pay ore to practically nothing. Going north from the recognized ore-shoot for several hundred feet the two facies irregularly alternate—the basic phase predominating. Within this distance development showed a few small widely separated bodies of ore. Beginning at a point about 700 feet north of the ore-shoot and extending for many hundreds of feet further the extension of the vein is covered with wash. Some little distance north of where the wash begins to cover the vein and about 100 feet west of the axis of the strike, there is a prominent exposure of the acidic (ore-bearing) phase of the andesite. The boundaries of this differentiation mass are ill-defined but it appeared that it would extend across the vein. Having already recognized the association between the developed ore-shoot and the acidic phase of the andesite the writer expressed the opinion that this portion of the vein, although covered with wash and far beyond demonstrated ore, would be found to carry pay values. Subsequent work corroborated the opinion.

Ore-bodies have been described as "the resultant of a number of fortuitous circumstances" and it is the opinion of the writer that magmatic differentiation, perhaps more than has been appreciated, is one of the factors which frequently plays an important rôle in the formation of ore-shoots.

FRED J. POPE.

REVIEWS

Die Wichtigsten Lagerstätten der "Nicht-Erze." (The More Important Occurrences of the Non-metallic Minerals. By Dr. O. STUTZER. Borntraeger, Berlin, 1911. Pp. 474, Figs. 108.

This volume is a comprehensive treatise on the geology of graphite, diamond, sulphur and phosphates, and is the first of a series of volumes dealing with all of the more important non-metallic minerals. Dr. Stutzer, who is a member of the geological faculty at the Royal School of Mines at Freiberg, Saxony, states that the work was undertaken at the suggestion of Dr. Beck and his work in a sense supplements the comprehensive treatise of the latter on the metalliferous deposits.

Graphite.—The chapter dealing with graphite is beyond question the best and most comprehensive treatise on the geology of this mineral that has ever been published. Dr. Stutzer is to be congratulated upon his exhaustive search of the voluminous literature but even more upon the way in which he has culled the unimportant from the important, and has interpreted the facts from the modern point of view. After a brief general discussion of the character and mode of occurrence of graphite the author proceeds to a description of individual deposits, usually including a discussion of their genesis. The chapter concludes with a short general discussion of the origin of graphite and brief statements in regard to uses and methods of refining, prices and values, and the artificial graphite production.

It is gratifying to note that Dr. Stutzer takes exception to the views of Weinschenck in regard to the origin of the Bohemian and Bavarian deposits. According to Weinschenck the graphite of these localities is of inorganic origin and was introduced along crevices and mineral cleavages by pneumatolytic action as an after effect of the intrusion of granite rocks. Weinschenck based this view of their origin in part upon the large amount of kaolinization observed in the graphitic rocks, regarding such kaolinization as another effect of pneumatolytic action. In the opinion of Stutzer and others the kaolinization and associated phenomena are due to weathering and are subsequent to and in no way related to the origin of the graphite. Stutzer shows from microscopic evidence that the graphite flakes in places interlock intimately with fresh

grains of quartz, feldspar and other minerals of the graphitic rock, and must have crystallized contemporaneously with them. He considers that these deposits were formed by the metamorphism of carbonaceous sediments. The agencies of this metamorphism are somewhat in question and may have been several, but the presence in some of the graphite deposits of a typical association of contact metamorphic minerals suggests the influence of the neighboring granitic intrusion.

In describing the famous Ceylon deposits, attention is directed to the presence of graphitic limestone in association with some of the workable deposits and to the presence in many of a typical association of contact metamorphic minerals including scapolite and wollastonite. Dr. Stutzer contents himself with summarizing the divergent views of others in regard to the origin of these deposits but the facts as presented will to most geologists be suggestive of metamorphic origin. Competent agents of metamorphism may be found among a large assortment of igneous rocks.

In his summary on the origin of graphite Dr. Stutzer recognizes as beyond question that graphite has in some instances crystallized contemporaneously with other mineral constituents of igneous rocks and is thus in a sense of inorganic origin. He calls attention, however, to the impracticability of determining in many instances whether such graphite was of deep-seated magmatic origin or was absorbed from bordering carbonaceous rocks. A number of undoubted instances of such absorption, such as the graphitic basalt of Greenland, are on record.

To the reviewer, the most significant feature of the data brought together in the graphite chapter is the patent fact that the great majority of graphite occurrences are of metamorphic origin and that in other instances where incomplete data makes a final judgment impossible, a metamorphic origin is to be suspected. With the possible exception of the Albert mine in Siberia, the occurrences of graphite in igneous rocks are small in amount and of no economic importance. The American occurrences accord completely with this interpretation.

EDSON S. BASTIN.

Diamond.—The section of the book devoted to diamond gives an excellent account of the various occurrences, the mineralogy, petrography and related scientific aspects of the subject being judiciously balanced so that the whole forms a very interesting and valuable treatment of the subject. The data for the South African mines have been largely taken from P. A. Wagner's "Die Diamantführenden Gesteine Südafrikas" as well as from other authors, notably from G. F. Williams' well-known book and M. Bauer's "Edelsteinkunde." Dr.

Stutzer, however, has so well digested his information as to present in relatively small compass essentially all that is known about the subject.

After a brief introductory statement giving the general properties of diamond, the various deposits are described in detail. The South African occurrences are naturally the most important and their description occupies 57 pages. The deposits in British South Africa are of two kinds, namely the "dry diggings," discovered in 1870, which are stocks or pipes of the altered igneous rock, the so-called kimberlite and in alluvial deposits, known as "river diggings," first worked in 1869 in the valley of the Vaal River.

The eruptive rock (kimberlite or blue ground) of these pipes has excited a great deal of interest, and any study of the genesis of the diamond involves also that of its matrix. The mineralogic and petrographic descriptions of this pipe rock are given with considerable detail by Dr. Stutzer. The kimberlite in many places contains inclusions which consist of fragments of the rocks surrounding the pipes, of deeper seated rocks and of formations now eroded away. The eruptive rock itself is now largely altered by serpentinization into the soft "blue ground," which shows important differences in character and in its tenor of diamonds, not only in the different mines but also in different parts of the same pipe. By the serpentinization of the kimberlite, an increase in volume of 13.5 per cent. has taken place and the effects of this movement explain many of the observations made both on the rocks surrounding the pipe and on the kimberlite itself. The contact between pipe and surrounding rock is sharp or is indicated by a zone of alteration. Contact metamorphic effects are seldom seen. The pipes are younger than the Trias.

Petrographically, the kimberlite is divisible into mica-poor and mica-rich types. These grade into each other, however, and are very closely related. The mica-poor type is found chiefly in pipes but also in dikes. Olivine was originally the most abundant mineral and formed 50 to 70 per cent. of the rock. The olivine crystals lie imbedded in a massive groundmass together with mica and a little pyrope garnet, enstatite, ilmenite and diopside. The mica-rich type occurs chiefly as dikes and has no definite groundmass. Large masses of olivine and mica lie in a granular mixture of smaller olivine and biotite between which calcite and serpentine have formed. Rounded (rarely angular) masses of red garnet, green diopside, black ilmenite, green enstatite, brown bronzite or brown mica are found and are thought to owe their shape to magmatic resorption. All told, twenty-one different kinds of nodular mineral aggregates are found, as for example, in addition to those just mentioned, garnet-diopside aggregates, olivine-bronzite aggregates, etc. The

most interesting of these are the diamond bearing eclogite nodules or boulders, which are coarse-grained aggregates composed chiefly of red garnet and green diopside. Less abundant are orthorhombic pyroxene, brown mica and magnetite. Blue kyanite is rare, diamond is even rarer and graphite is exceptional. The diamond crystals found in these eclogite nodules all have sharp edges and corners, in contrast with the rounded forms mined in the blue ground. The two views on the origin of these eclogite nodules are: (1) that they are inclusions of a deeply buried schist through which the kimberlite magma broke and (2) that they are magmatic differentiations of the magma itself. The presence of kyanite (hitherto found only in crystalline schists) in these nodules and its absence in the kimberlite, forces one to assume an unusual disturbance of chemical equilibrium in the magma if he adopts the latter view. The chief points in favor of the magmatic differentiation theory are that the eclogite boulders are found in nearly all of the pipes of the region, so that if these are inclusions, eclogite must exist over an extensive area. No eclogite exposures, however, have been found anywhere in South Africa. Moreover, other eruptives such as the abundant diabase, do not show any inclusions of eclogite. The presence of diamonds in the eclogite is the best evidence for their magmatic segregation as otherwise one must assume two entirely different modes of genesis of the diamond.

As regards the genesis of the diamond the author states that the mineral must be considered as an accessory of the kimberlite. The view of Carvel Lewis that the diamond is formed by the action of the kimberlite on included carbonaceous shales is untenable because fragments of such shale in the kimberlite are very little acted upon. Moreover, no diamond has ever been found in the shale, diamond-bearing pipes occur in formations which do not contain any carbonaceous shales and diamond is found as inclusions in garnet, diopside and olivine, as well as in the eclogite boulders, conditions of association entirely distinct from those of the carbonaceous shales. Against the idea that the diamond came from a deep-seated eclogite formation which was shattered by the eruption of the pipes are the facts that some pipes rich in diamond are not rich in eclogite, in fact, in some mines the garnet-diopside aggregates are very rare or entirely unknown. That the diamond is a primary constituent of the kimberlite is indicated by the differences in the diamonds from different mines and from different parts of the same mine, by the distribution of similar diamonds in vertical columns in the pipes, by the finding of a diamond enclosed in olivine, by the occurrence of microscopic diamond and graphite in the ground-mass of the kimberlite and

by experiments showing that the kimberlite when artificially fused can dissolve the diamond.

The development and workings of the mines are briefly described followed by statistics of production. In the description of the river diggings whose diamonds are superior in quality to those of the pipes, it is stated that the original matrix of the diamond is still unknown, though an olive rich diabase seems the most probable. An occurrence of blue-ground, very similar to that of Kimberly, is described in German South West Africa, though no diamonds have as yet been found in it. Diamonds occur here, however, in the coast sands. Their origin is uncertain.

The Brazilian diamond deposits occurring in sand and conglomerate are briefly but well described. The source of these alluvial diamonds has yet to be found.

The localities where isolated diamonds have been found in the United States are briefly mentioned followed by a short description of the Arkansas field. While the peridotite rock forming the diamond matrix in Arkansas is somewhat similar in petrographic character to that of South Africa, the abundant inclusions of foreign rock fragments so characteristic of the true kimberlite are entirely absent from the Arkansas rock.

In Australia, two diamonds have been found in a hornblende diabase. All other diamonds in Australia come from secondary deposits, sand or conglomerate formations. Similarly the Borneo deposits of diamonds, whose origin is unknown, lie in sand and conglomerate layers. The Indian diamonds, of great historical interest, are found in old sandstones and conglomerates. It is very doubtful whether pegmatite is the true home of the two diamonds found in soil derived from pegmatite. In the province of Shantung, China, diamonds are found in river conglomerates, in tuffs and in sandstone.

Short chapters on the occurrence of diamonds in meteorites, on artificial diamonds, and on uses and valuation, close the section.

WALDEMAR T. SCHALLER.

Sulphur.—In this chapter are brought together from widely scattered sources in many languages descriptions of all the well known and most of the less important sulphur deposits of the world. The method of presentation is geographical.

As a matter of course the sulphur deposits of Italy are given first place, since these always have been the largest and in fact the only really important source of sulphur until recent years when Louisiana sulphur has become a prominent factor in the world's market. Though

Japan ranks third among the sulphur-producing countries, her production is very small when compared with that of either Italy or the United States, even though until 1902 she held second rank.

When Italian sulphur is mentioned one naturally thinks of the Sicilian product. Sicily, though the most important producing district of Italy, is only one among four, the three others being (1) Romagna and Marken, (2) Tuscany (Sienna) and (3) Campania and Calabria. The fact that both the first and third districts mentioned are of more consequence than Japan, will serve to indicate that Italian sulphur-producing areas outside of Sicily, are of notable importance, even though very little is heard of them.

Among the other European deposits described are those in the Caucasus and Transcaspia, as well as other less important occurrences of Russia; those of Southern France, Spain, and Greece, and the deposits of Austria-Hungary, located at Radoboj (Croatia) and Swoszowice (Galicia). In Asia the Japanese deposits are the most important and are described at some length, and the less important deposits in Asia Minor, Palestine, Persia and India are mentioned. In the United States are described the deposits of Louisiana, Nevada, Utah, Texas and Wyoming and to the south the most important occurrences in Mexico. Some attention in given also to deposits in Chile, Peru, Algeria, Morocco and Australasia. Thus it will be seen that the world's fields have been effectually covered and practically nothing omitted—certainly nothing of importance. The descriptions include more or less detailed accounts of the mineralogy and geology of the sulphur beds, notes on origin, technology or mining methods and statistics.

A popular misconception regarding the deposition of sulphur is corrected in the concluding chapter, on origin. The majority of and the most important sulphur deposits are shown to be of sedimentary origin. Only a few deposits may be directly ascribed to volcanic origin, and of these the Japanese deposits alone are of any considerable importance. The most important sulphur occurrences are modified sedimentary deposits but the chemistry of the reactions which have produced them, has not yet been completely and satisfactorily explained.

In all of the bedded sulphur deposits the sulphur layers are limited to certain members of the series and are not present in the form of irregular stocks or masses traversing different stratigraphic horizons. Thus a contemporaneous deposition is indicated for the original sulphur-bearing material. In the Sicilian deposits, in which the commercial development is most advanced and where the best opportunities for study are to be found, both in the hanging wall and the foot wall, there

is not a trace of sulphur. An epigenetic explanation of the sulphur deposits would have to explain this negative evidence. This and other detailed evidence points to the sedimentary origin of the Sicilian sulphur deposits,

The scope and comprehensiveness of the work, the details of the descriptive matter, the value of the bibliographies and the clearness of the exposition on the genesis of sulphur, make this section a distinct contribution to the geologic literature of the non-metals, and a valuable reference work for the scientist and for the engineer whose interests are not merely local. W. C. PHALEN.

Phosphates.—Deposits of phosphate minerals may, as suggested by Dr. Stutzer, be divided into three groups: (1) Those which are of value because of their phosphorus content—phosphorite and apatite; (2) monazite, valuable for its content of rare earths; and (3) gem minerals, such as turquoise, lazulite, etc. Only the first group is considered in this section which contains nearly 200 pages. This group is treated under three heads, (1) apatite deposits (pp. 275–298), (2) phosphorite ("phosphate rock") deposits (pp. 298–417), and (3) guano deposits (pp. 417–429). The origin of these deposits and the distribution of phosphoric acid in nature are discussed at length. Sections on the application, extraction and manufacture, valuation, price, and production of the phosphates, with samples of phosphate contract blanks, close the volume.

In his introductory remarks on the mineralogy of the phosphate deposits, Dr. Stutzer states that the principal component of phosphorite is amorphous tricalcium phosphate, $Ca_3(PO_4)_2$ whereas, according to the recent studies of Lacroix,[1] it may consist essentially of the amorphous mineral collophanite, $3[Ca_3(PO_4)_2][CaCO_3]nH_2O$ with smaller amounts of the crystallized francolite and dahllite.

Interesting short chapters are given on the form of the phosphate deposits, on their differences in depth, surrounding rocks, content of phosphoric acid, structure such as nodular, sedimentary layers, chemically reworked deposits and breccias. Though various classifications (stratigraphic, petrographic, genetic) have been proposed, the only ones of practical value are the geographical and the one based on the quality of the rock. The geographical basis is the one used in this work. It is of interest to note that deposits of phosphate minerals are known throughout the geological ages, from the Archean to the recent. The many localities where phosphate deposits are found and mined are well described in detail. Maps and geological sections, chemical analyses

[1] *Comptes Rendus*, Vol. 150, p. 1213. "Mineralogie de la France," Vol. 4, p. 555.

and statistics of production add greatly to the value of the descriptions.

In discussing the genesis of the phosphate deposits, Dr. Stutzer divides them into those of inorganic and those of organic origin.

The inorganic deposits lie in Norway, Canada, Sweden and Spain. The Norwegian chlorapatite and the Canadian fluorapatite have a similar genetic origin being considered as pegmatitic-like eruptives or injection veins. Pneumatolytic action played a large part in the formation of the Canadian veins. In Spain a trachyte is so richly impregnated with fluorapatite as to be locally worked. At other places in Spain are veins and stocks in limestone, considered as metasomatic replacements, in schists and in granite. The phosphorite veins in granite, in places grading into quartz-apatite veins, are thermal deposits. The deposits at Quercy, France, are due to thermal springs but the source of the phosphorus is uncertain. Similarly the Lahn and Dill deposits in Germany may be ascribed to either inorganic or organic sources.

The organic deposits are of three general classes: (1) Primary, sedimentary ones, either land accumulation of bones or guano, or deposits formed under water by precipitation of calcium phosphate, or by concentration processes or by accumulation of organic material (teeth, bones, etc.) from animals. (2) Chemically reworked deposits such as former guano deposits which by gradual alteration react on the underlying limestone (coral) to form phosphate rock, or by solution and redeposition as for example, by thermal metasomatism. (3) Mechanically reworked deposits of an original sedimentary, organic character.

An interesting section is the one on the distribution of phosphoric acid in nature. The percentages of calcium phosphate for various substances are given as: for dry bones 60 per cent, for teeth 70 per cent, for crab and snail shells 7 per cent. In vegetation phosphoric acid is present in various amounts, thus one pound phosphoric acid is found in 100 pounds of corn, and in 1,200 pounds of green feed.

In tracing the original source of all the phosphate deposits, one comes to a single primary source, namely the apatite of igneous rocks. By the decomposition of these rocks, the phosphoric acid passes into the soils and the seas from which it is extracted and concentrated by plant life. Animals feeding on plants or on other herbivorous animals further concentrate the phosphoric acid. Then by mechanical or by chemical processes the remains of the animals are still further concentrated so that the story of the genesis of the phosphate deposits is one long story of concentration.

In closing, only words of commendation can be said of the phosphate section of Dr. Stutzer's book. It is a carefully prepared work, all the parts of which are of high merit.

WALDEMAR T. SCHALLER.

RECENT LITERATURE ON ECONOMIC GEOLOGY.

COMPILED BY

G. F. LOUGHLIN.

METALLIFEROUS DEPOSITS.

GOLD AND SILVER.

Geology of the Cobalt District, Ontario, Canada. By R. E. HORE. Bull. A. I. M. E. No. 53, 1911.

General geology and petrology, structure of the deposits, influence of the country rock, character and production of the ores, origin of the deposits.

Genesis of the Leadville Ore Deposits. Bull. A. I. M. E. No. 50, 1911, pp. 195–197.

Discussion by W. M. Webb of a paper by M. Boehmer, expressing some doubt as to the latter's conclusions.

The Greatest Gold Mine of France. By T. T. READ. The Mining Magazine (London). IV, 3, 1911, pp. 209–212.

A brief general account. Ore occurs in quartz veins in schist.

IRON.

The Iron Ore Deposits of the Moa District, Oriente Province, Island of Cuba. By J. S. Cox, JR. Bull. A. I. M. E. 51, 1911, pp. 199–92.

Origin of the Iron Ores of Central and Northwestern Cuba. By C. K. LEITH and W. J. MEAD. Bull. A. I. M. E. 51, 1911, pp. 217–230.

Occurrence, Origin, and Character of the Surficial Iron Ores of Camaguey and Oriente Provinces, Cuba. By A. C. SPENCER. Bull. A. I. M. E. 51, 1911, pp. 231–238.

The Mayori and Moa Iron Ore Deposits in Cuba. By C. W. HAYES. Bull. A. I. M. E. 51, 1911, pp. 239–246.

Characteristics and Origin of the Brown Iron Ores of Camaguey and Moa, Cuba. By W. L. CUMMINGS and B. L. MILLER. Bull. A. I. M. E. 51, 1911, pp. 247–268.

Exploration of Cuban Iron Ore Deposits. By D. E. WOODBRIDGE. Bull. A. I. M. E. 51, 1911, pp. 269–282.

TIN.

Tin Deposits of El Paso County, Texas. By R. CHAUVENET. Proc. Col. Scientif. Society. Vol. IX, pp. 451–458, 1911.

Brief descriptions of the ore occurrence (impregnating granite along narrow pegmatitic dikes) and preliminary methods of working.

NON-METALLIC DEPOSITS.

Gypsum.

The Gypsum Theory. By W. M. STEPHENSON. Oil and Gas Journal. Vol. 9, No. 46, 1911, pp. 8–12.

OIL AND GAS.

Oil and Gas in Monoclinal Dips. By F. G. CLAPP. Oil and Gas Journal. Vol. 9, No. 46, 1911, pp. 6–8.

The Production of Petroleum in 1909. By D. T. DAY. Adv. Chap. from Min. Res. of U. S. for 1909.

The Caddo Oil and Gas Field, Louisiana. By W. E. HOPPER. Bull. A. I. M. E. No. 52, 1911, pp. 283–310.

Gives history, geology, drilling operations, treatment of product, consumption of oil and gas, cost and life of the field.

Oil Fields of Mexico. Notes by H. L. WOOD. Oil and Gas Journal. April 6, 13, and 20, 1911.

SALT.

Der Verband für die Wissenschaftliche Erforschung der Kalisalzlage Stätten. By J. H. VAN'T HOFF. Kgl. Akad. d. Wiss. Berlin, 1910, XXXIX, pp. 772–786.

STONE.

The Geology of Building Stones. By J. A. HOWE. Arnold's Geological Series. London, 1910, pp. 8 + 455.

Geological and mineralogical introduction, chapters on the different types of stone, decay of stone, and details of testing. Appendices give lists of principal quarries and bibliography.

WATER.

Well-Drilling Methods. By I. Bowman. U. S. Geol. Survey, W–S. Paper 257, 1911.

Begins with short account of underground waters and water-bearing formations, and the history of well-drilling; then considers the several methods of drilling, features of well construction, contamination of wells, capacity of wells, measurement of depth, deflection of drill hole, and cost of well sinking.

REGIONAL REPORTS.

Mineral Resources of Johnstown, Pennsylvania and Vicinity. By W. C. Phalen and Lawrence Martin. Bull. 447. U. S. Geol. Survey, 1911.

Describes the several formations and the mineral resources (coal, clay and shale, limestone and cement materials, building stone, etc., glass sand, iron ores, and water).

Bibliography of Tennessee Geology, Soils, Drainage, Forestry, Etc. By Elizabeth Cockrill. Extract (B) from Bulletin No. 1. Tenn. Geol. Survey, 1911.

Biennial Report of the State Geologist (Mo.). By H. A. Buehler. Mo. Bureau of Geology and Mines. 1909–1910.

Chap. I., work during biennial period. II., Future Work. III., Coal field of No. Missouri. IV., Reconnaissance work. V., Geology of the Newburg area. VI., Chemical analyses. Financial statement.

The Ore Deposits of New Mexico. By W. Lindgrin, L. C. Graton, and C. H. Gordon. Prof. Paper 68, U. S. Geol. Survey, 1910. Pp. 361 with 22 plates and 33 figures.

Part I describes the geology and metal deposits, precambrian deposits, contact-metamorphic deposits, veins connected with tertiary intrusives, copper deposits due to oxidizing surface waters, vein and replacement deposits in limestone (not contact-metamorphic) veins connected with tertiary volcanoes, the hot springs at Ozo Caliente and their deposits, lead and copper veins of doubtful affiliation, placers, and copper deposits in sand-stone. Part II., detailed descriptions.

Reconnaissance of the Geology and Mineral Resources of Prince William Sound, Alaska. By U. S. Grant and D. F. Higgins. Bull. 443. U. S. Geol. Survey, 1910.

Administrative Report of Tennessee State Geological Survey, 1910. By G. H. Ashley. Bull. 4. Tenn. Geol. Survey, 1911.

West Virginia Geological Survey. I. C. WHITE, State Geologist. Vol. V. Forestry and wood industries. Bull. II., Levels and Coal analyses.

ORE DEPOSITS.

Genesis of Ore Deposits. By G. J. BANCROFT. Proc. Col. Sci. Society. Vol. X., pp. 1–16, 1911.

Discusses subject under the following headings: (1) Deposits which are part of the original magma; (2) Deposits in fissures, cavities, or porous rocks resulting from emanations from the magma; (3) Deposits resulting from the leaching and reconcentration by meteoric waters of either of the first two classes; (4) Deposits resulting from erosion and reconcentration of either or all the first three classes; (5) Deposits resulting from reconcentrations of metal from non-eruptive rocks.

Origin of the Thermal Waters, Yellowstone National Park. By ARNOLD HAGUE. Bull. G. S. A. Vol. 22, No. 1, 1911, pp. 103–122.

A presentation of detailed evidence to show that the hot spring and geyser waters are of meteoric origin.

Recently Discovered Hot Springs in Arkansas. By A. H. PURDUE. Jour. Geology. XIX., 3, 1911, pp. 271–275.

Gives location and analyses. Heat possibly due to flowing of groundwater over hot igneous rocks of cretaceous or post-cretaceous age.

UNCLASSIFIED.

Mineral Resources of the United States, Calendar Year 1909. U. S. Geol. Survey, Washington, D. C. By F. L. HESS.

Advance chapters on lithnum, and on tungsten, nickel, cobalt, vanadium, titanium, molybdenum, uranium, tantalum and tin.

The Publications of the United States Geological Survey (not including topographic maps). Washington, D. C., February, 1911.

SCIENTIFIC NOTES AND NEWS[1]

REGULATIONS FOR the establishment of Local Sections of the American Institute of Mining Engineers have been formulated by a special committee comprising Messrs. Charles F. Rand, E. Gybbon Spilsbury, Arthur L. Walker, Joseph W. Richards, Karl Eilers, Charles Kirchhoff and Joseph Struthers, secretary. Permission has been granted to organize and establish a local section in San Francisco and in New York City.

THE NEW YORK Mineralogical Club held its annual meeting on May 10. George E. Ashby, James G. Manchester, W. G. Levison and others, discussed "The Minerals of Kinkel's Quarry, Bedford Hills, New York."

AT A RECENT MEETING of the Section of Geology and Mineralogy of the New York Academy of Sciences the following papers were read: Dr. E. O. Hovey, "Copper Queen Mine, Bisbee, Arizona"; Mr. James G. Manchester, "New Discovery of Gem Stones on Manhattan Island"; Professor James F. Kemp, "The Saratoga Mineral Springs"; Professor A. W. Grabau, "Some Siluric Coral Reefs of Europe."

AT RECENT meetings of the Geological Society of Washington the following papers were read. P. S. Smith, "Notes of the Geology of Koykuk-Kobuk Region, Alaska"; E. W. Shaw, "A New System of Quaternary Lakes in the Mississippi Basin"; Arthur Hollick, "Discussion of the Cretaceous and Tertiary floras of Alaska"; N. L. Bowen, "The Analcite-Nephelite series"; G. C. Martin, "The Classification of Higher Grade Coals"; Waldemar Lindgren, "On the Classification of Ore Deposits."

[1] Geologists, mining engineers and others interested in applied geology are invited to keep the editor informed of new investigations of mining districts or scientific studies undertaken by them, together with such other scientific and personal items as may come to their notice.

FREDERICK G. CLAPP spent the month of May in examining oil properties in the state of Vera Cruz, Mexico.

PROFESSOR GEORGE F. KAY, who has been for four years professor of petrology and economic geology in the University of Iowa, has been elected head of the department of geology to succeed Professor Samuel Calvin, who died recently. Professor Kay has also been chosen by the Geological Board to succeed Professor Calvin as Director of the State Geological Survey.

NEW appointments and promotions at Stanford University for the academic year beginning August 1, 1911, are as follows:

New Appointments.—Noah F. Drake, associate professor of economic geology. Dr. Drake is a graduate, A.B., A.M. and Ph.D., of Stanford University; professor of geology and mining in Imperial Pei Yang University, Tientsin, China, since 1898.

Promotions.—David M. Folsom, to be associate professor of mining; Galen H. Clevenger, to be associate professor of metallurgy.

DR. CLINTON R. STAUFFER, assistant professor of geology at the School of Mining, Kingston, Canada, has been appointed associate professor of geology in Western Reserve University.

PROFESSOR LOUIS DOREMUS HUNTOON, M.E., of the department of mining and metallurgy, Sheffield Scientific School, Yale University, has resigned his position to engage in work in the Canadian gold fields.

DR. JOHN M. CLARKE, state geologist and director of science in the New York State Education Department, gave an illustrated lecture before the departments of geology and biology of Colgate University on the evening of May 3. His subject was "The Magdalen Islands and the Bird Rocks."

ON April 13, Professor Heinrich Ries, professor of economic geology, Cornell University, lectured at the University of Alabama on the economic geology of the Canadian northwest.

MR. F. E. MATTHES, of the U. S. Geological Survey, is delivering a course of twelve illustrated lectures with accompanying

laboratory work before the students of the University of Michigan, the subject of the lectures being, "Topographic Mapping." On May 3, by invitation of the Michigan Chapter of Sigma Xi, Mr. Matthes told in a popular lecture "How the Map of the Grand Canyon was made." The maps of the Grand Canyon, Yosemite Valley and the new Glacier National Park have all been prepared by Mr. Matthes, who is now engaged upon the map of the new Mt. Ranier National Park.

THE research committee of the National Geographic Society of Washington has made an appropriation of $5,000 for continuing the glacier studies of the two previous years in Alaska. The work, beginning in June, 1911, will be done by Professor R. S. Tarr, of Cornell University, and Professor Lawrence Martin, of the University of Wisconsin, who have directed the National Geographic Society's Alaskan expeditions of 1909 and 1910 in the Yakutat Bay, Prince William Sound, and lower Copper River regions. The 1911 expedition will study briefly a number of regions of glaciers not previously investigated by the National Geographic Society, although partially mapped by the Alaska Division of the U. S. Geological Survey, the Boundary Commissions, etc. Work will be done on the present ice tongues and the results of glaciation in the mountains and plateaus of parts of the interior and some of the fiords of southeastern Alaska, the former having lighter rainfall and smaller ice tongues than the Yakutat Bay and Prince William Sound regions.

Mr. J. B. Tyrrell of Toronto has left for a short visit to England. His address will be 224 Salisbury House, London, E. C.

The Oklahoma Geological Survey announces the appearance of Bulletin No. 7, a Preliminary Report on the Clays and Clay Industries of Oklahoma. This Report will be sent to anyone upon the receipt of 11 cents in stamps to cover postage.